ATOMIC & MOLECULAR PHYSICS

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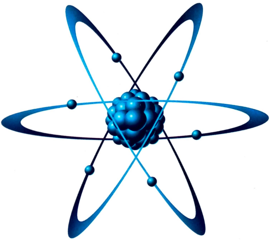

Assignment & Previous Years' Question

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ATOMIC & MOLECULAR PHYSICS

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Assignment-1 : Atomic Spectra (Hydrogen Atom)

1. An electron is initially in the n = 3 state and the average lifetime of this state is 10^{-8} sec. The number of revolution that the electron takes before making a transition to the n = 2 state, is

   (a) 2.4×10^{4} (b) 2.4×10^{5} (c) 2.4×10^{6} (d) 2.4×10^{7}

2. The wavelength of seventh line of the Balmer series of hydrogen atom is

   (a) 384 nm (b) 424 nm (c) 456 nm (d) 512 nm

3. The energy required to remove an electron from a singly-ionized Helium atom which in the n = 8 state, is

   (a) 0.213 eV (b) 0.51 eV (c) 0.85 eV (d) 1.11 eV

4. The momentum of the photon emitted by a hydrogen atom making a direct transition from an excited state n = 10 to the ground state, is

   (a) $2.8\times10^{-27}\,kg\ m\ s^{-1}$ (b) $7.2\times10^{-27}\,kg\ m\ s^{-1}$ (c) $7.2\times10^{-26}\,kg\ m\ s^{-1}$ (d) $2.8\times10^{-26}\,kg\ m\ s^{-1}$

5. An accelarated beam of electrons bombards a sample of hydrogen and the first line of Paschen series is emiited. The electrons must have been accelarated through a minimum potential difference of

   (a) 12.8 V (b) 14.1 V (c) 16.7 V (d) 19.1 V

6. A mixture of ordinary hydrogen and tritium is excited and its spectrum is studied. The shift in wavelength for the H_α lines of the two kinds of hydrogen, is

   (a) 2.4 A^0 (b) 3.3 A^0 (c) 5.4 A^0 (d) 6.7 A^0

7. The temparature at which the average molecular kinetic energy in the gaseous hydrogen will be equal to the binding energy of the hydrogen atom, is

   (a) $10^{4}\,K$ (b) $10^{5}\,K$ (c) $10^{6}\,K$ (d) $10^{7}\,K$

8. Consider the spectral line resulting from the transition n = 2 and n = 1 in the atoms and ions given below. The shoertest wavelength will be produced by

   (a) Hydrogen atom (b) Deutron atom
   (c) Singly ionized helium (d) Doubly ionized lithium

9. A gas of monochromatic hydrogen is bombarded with a stream of electrons that have been accelerated from rest through a potenial difference 12.75 Volts. In the emission spectra one cannot observe

   (a) Lymam series (b) Balmer Series (c) Paschen Series (d) Pfund Series

10. If the principal quantum number and the azimuthal quantum number in the relativistic model of the atom are 3 and 1 respectively, then the magnitude of the semi-minor axis 'b' in terms of the semi major axis 'a' is given by

    (a) b = a/3 (b) b = 2a/3 (c) b = a/2 (d) b = a

11. Given that the ground state energy of the hydrogen atom is -13.6 eV, then the ground state energy of positronium (which is a bound state of an electron and a positron) is **[NET Dec. 2011]**

    (a) 6.8 eV (b) -6.8 eV (c) -13.6 eV (d) 13.6 eV

12. A muon $\left(\mu^-\right)$ from cosmic rays is trapped by a proton to form a hydrogen-like atom. Given that a muon is approximately 200 times heavier than an electron, the longest wavelength of the spectral line (in the analogoue of the Lyman series) of such an atom will be **[NET June 2013]**

    (a) 5.62 A^0 (b) 6.67 A^0 (c) 3.75 A^0 (d) 13.3 A^0

13. If R_1 is the value of the Rydeberg constant assuming the mass of the nucleus to be infinitely large compared to that of an electron and R_2 is the value of the Rydeberg constant taking the nuclear mass to be 7500 times the mass of the electron, then the ratio $\frac{R_2}{R_1}$ is **[GATE 2002]**

(a) a little less than unity
(b) a little more than unity
(c) infinitely small
(d) infinitely large

14. If the wavelength of the first line of the Balmer series in the hydrogen spectrum is λ, then the wavelength of the first line of the Lyman series is **[GATE 2002]**

(a) $\frac{27}{5}\lambda$
(b) $\frac{5}{27}\lambda$
(c) $\frac{32}{27}\lambda$
(d) $\frac{27}{32}\lambda$

15. Consider the Bohr model of the hydrogen atom. If α is the fine structure constant, then the velocity of the electron in its lowest orbit is **[JEST 2012]**

(a) $\frac{c}{1+\alpha}$
(b) $\frac{c}{1+\alpha^2}$ or $(1-\alpha)c$
(c) $\alpha^2 c$
(d) αc

16. The binding energy of the hydrogen atom (electron bound to proton) is 13.6 eV. The binding energy of positronium (electron bound to positron) is **[JEST 2012]**

(a) 13.6/2 eV
(b) 13.6/1810 eV
(c) 13.6×1810 eV
(d) 13.6×2 eV

17. If a proton were ten times lighter, then the ground state energy of the electron in a hydrogen atom would be **[JEST 2013]**

(a) less
(b) more
(c) same
(d) less, more or equal depending on the electron mass

18. A hydrogen atom in its ground state is collided with an electron of kinetic energy 13.377 eV. The maximum factor by which the radius of the atom would increase is **[JEST 2014]**

(a) 7
(b) 8
(c) 49
(d) 64

19. Given that the ionization energies of Hydrogen $\left({}^1H\right)$ and Lithium $\left({}^3Li\right)$ are 13.6 eV and 5.39 eV respectively. The effective nuclear charge experienced by the valence electron of the ${}^3Li$ atom may be estimated in terms of proton charge *e* as **[TIFR 2011]**

(a) 3.00 *e*
(b) 1.59 *e*
(c) 1.26 *e*
(d) 0.63 *e*

20. Consider the high excited states of a hydrogen atom corresponding to large values of the principal quantum number (n>>1). The wavelength λ of a photon emitted due to an electron undergoing a transition between two such states with consecutive values of n $\left(i.e.\ \psi_{n+1}\to\psi_n\right)$ is related to the wavelength λ_α of the K_α line of hydrogen by **[TIFR 2012]**

(a) $\lambda=\frac{n^3}{8}\lambda_\alpha$
(b) $\lambda=\frac{3n^3}{8}\lambda_\alpha$
(c) $\lambda=n^2\lambda_\alpha$
(d) $\lambda=\frac{4}{n^2}\lambda_\alpha$

21. The velocity of an electron in the ground state of a hydrogen atom is v_H. If v_p be the velocity of an electron in the ground state of positronium, then **[TIFR 2013]**

(a) $v_p=v_H$
(b) $v_p=2v_H$
(c) $v_p=\frac{v_H}{2}$
(d) $v_p=\sqrt{2}v_H$

22. A sample of ordinary hydrogen $\left({}_1^1H\right)$ gas in a discharge tube was seen to emit the usual Balmer spectrum. On careful examination, however, it was found that the H_α line in the spectrum was split into two fine lines, one an intense line at 656.28 nm and the other a faint line at 656.04 nm. From this, one can conclude that the gas sample had a small impurity of **[TIFR 2015]**

(a) ${}_1^3H$
(b) ${}_1^2H$
(c) ${}_2^4He$
(d) H_2O

23. The electron in a hydrogen atom with a radius equal to first Bohr radius has a velocity equal to

(a) $\frac{C}{5}$ (b) $\frac{C}{10}$ (c) $\frac{C}{137}$ (d) $\frac{C}{8}$

24. The numerical value of the radius of the first orbit of hydrogen as

(a) 0.529 nm (b) 0.0529 Å (c) 5.29 Å (d) 0.0529 nm

25. When an electron jumps from the fourth orbit to the second orbit, one gets

(a) The first line of P fund series (b) Second line of Lyman series
(c) Second line of Paschen series (d) Second line of Balmer series

26. The Bohr formula when utilised to calculate ionization energy. He is found to yield a result higher than experimental value because of

(a) Electron- electron interaction (b) Spin orbit interaction
(c) Spin-spin interaction (d) None of above

27. The first line of the Lyman series of a ten times ionized Na atom has a wavelength of about

(a) 0.1 Å (b) 1Å (c) 10Å (d) 100Å

28. If v is the velocity of the electron in a stationary orbit of radius r, the orbital frequency of the electron is:

(a) $\frac{\upsilon}{2\pi r}$ (b) $\frac{\upsilon}{r}$ (c) $\frac{\upsilon}{\pi r}$ (d) $\frac{2\pi r}{\upsilon}$

29. The length of the semi-major axis of an electron in an elliptical orbit is determined

(a) only by the principal quantum number
(b) only by the azimuthal quantum number
(c) both by principal quantum number and azimuthal quantum numbers
(d) none of these

30. When the azimuthal quantum number n_ϕ is zero

(a) The ellipse reduces to a straight line (b) The ellipse reduces into a circle
(c) The ellipse reduces to a parabola (d) none of these

31. The doublets observed in alkali spectra are due to

(a) Screening of the K-electrons (b) Spin-orbit interaction of the electron
(c) Pressure of isotopes (d) None of these

32. Two states of an atom have definite parities. An electric dipole transition between these states is:

(a) Allowed if both the states have even parity.
(b) Allowed if both the states have odd parity.
(c) Allowed if the two states have opposite parities.
(d) Not allowed unless a static electric field is applied.

33. Let E_1, E_2, E_3 be the first three energy levels of a hydrogen atom. Consider the ratio $(E_3 - E_2)/(E_2 - E_1)$. Neglecting the fine structure condition this ratio is approximately equal to

(a) $\frac{27}{5}$ (b) $\frac{1}{27}$ (c) $\frac{27}{4}$ (d) $\frac{5}{27}$

34. The shortest wavelength in the Balmer series of the Hydrogen atom occurs due to

(a) transition from the 3s to 2s (b) ionization from the 2s level
(c) ionization form th 1s level (d) transition from 2s to 1s level

35. A hydrogen atom is in the 2p state. To what state or states can it go by radiating a photon in an allowed transition?

(a) 1s, 2s, 3p, 3d (b) 1s, 2s, 3s, 3p (c) 2s, 3p, 3d (d) 1s, 2s

36. An atom in an excited sate $\psi_{n\ell m}$ can make a radiative transition to a state $\psi_{n'\ell' m'}$ if

(a) $\int_{-\infty}^{\infty} \psi^{*}_{n'\ell' m'}\, \overline{r}\, \psi_{n\ell m}\, dV \neq 0$

(b) $\int_{-\infty}^{\infty} \psi^{*}_{n'\ell' m'}\, \overline{r}^{2}\, \psi_{n\ell m}\, dV \neq 0$

(c) $\int_{-\infty}^{\infty} \psi^{*}_{n'\ell' m'}\, \psi_{n\ell m}\, dV = \delta_{nn'}\, \delta_{\ell\ell'}\, \delta_{mm'}$

(d) $\int_{-\infty}^{\infty} \psi^{*}_{n'\ell' m'}\, \overline{r}\, \psi_{n\ell m}\, dV = 0$

37. The longest wavelength in the spectral series of the Hydrogen atom occurs due to

(a) transition from $n = \infty$ to $n = 1$
(b) ionization from 1s level
(c) transition from 2s to 1s level
(d) ionization from n = 100

Statement for Linked Answer type Q. 38 and Q. 39.

Positronium is an atom formed by an electron and a positron. The mass of a positron is the same as that of an electron and its charge is equal in magnitude but opposite in sign to that of an electron. The positronium atom is thus similar to the hydrogen atom with the positron replacing the proton.

38. The binding energy of a positronium atom is:

(a) 13.6 eV
(b) 6.8 eV
(c) 27.2 eV
(d) 3.4 eV

39. If a positronium atom makes a transition from the state with n = 3 to a state with n = 2, the energy of the photon that is emitted in this transition is closest to

(a) 1.88 eV
(b) 0.94 eV
(c) 1.13 eV
(d) 2.27 eV

40. Which of the following transitions is NOT allowed in the case of an atom, according to the electric dipole radiation selection rule? **[GATE 2016]**

(a) $2s - 1s$
(b) $2p - 1s$
(c) $2p - 2s$
(d) $3d - 2p$

41. For an electron in hydrogen atom, the states are characterized by the usual quantum numbers n, l, m_l. The electric dipole transition between any two states requires that

(a) $\Delta\ell = 0,\ \Delta m_\ell = 0, \pm 1$
(b) $\Delta\ell = \pm 1,\ \Delta m_\ell = \pm 1, \pm 2$
(c) $\Delta\ell = \pm 1,\ \Delta m_\ell = 0, \pm 1$
(d) $\Delta\ell = \pm 1,\ \Delta m_\ell = 0, \pm 2$

42. The energy of an electron in the ground state of the He atom is –79 eV. Considering the Bohr model of the atom, what would be 10 times the first ionization potential for a He^{+} ion, in units of eV ? **[TIFR 2017]**

43. Hydrogen atoms in the atmosphere of a star are in thermal equilibrium, with an average kinetic energy of 1 eV. The ratio of the number of hydrogen atoms in the 2nd excited state $(n = 3)$ to the number in the ground state $(n = 1)$ is **[TIFR 2017]**

(a) 3.16×10^{-11}
(b) 1.33×10^{-8}
(c) 3.16×10^{-8}
(d) 5.62×10^{-6}

44. Consider Rydberg (hydrogen-like) atoms in a highly excited state with n around 300. The wavelength of radiation coming out of these atoms for transitions to the adjacent states lies in the range:

(a) Gamma rays (λ~pm)
(b) UV(λ~nm)
(c) Infrared (λ~μm)
(d) RF(λ~m)

45. The electronic ground state energy of the Hydrogen atom is –13.6 eV. The highest possible electronic energy eigenstate has an energy equal to **[GATE 2017]**

(a) 0
(b) 1 eV
(c) +13.6 eV
(d) ∞

46. Positronium is an atom made of an electron and a positron. Given the Bohr radius for the ground state of the Hydrogen atom to be 0.53 Angstroms, the Bohr radius for the ground state of positronium is ________ Angstroms. (up to two decimal places). **[GATE 2017]**

47. Let T_g and T_e be the kinetic energies of the electron in the ground and the third excited states of a hydrogen atom, respectively. According to the Bohr model, the ratio $\frac{T_g}{T_e}$ is **[GATE 2018]**

(a) 3
(b) 4
(c) 9
(d) 16

48. If the fine structure splitting between the $2\,^2P_{3/2}$ and $2\,^2P_{1/2}$ levels in the hydrogen atom is $0.4\ \text{cm}^{-1}$, the corresponding splitting in Li^{2+} will approximately be **[NET Dec. 2017]**

(a) $1.2\ \text{cm}^{-1}$ (b) $10.8\ \text{cm}^{-1}$ (c) $32.4\ \text{cm}^{-1}$ (d) $36.8\ \text{cm}^{-1}$

49. The Hydrogen α - line H_α of wavelength $\lambda = 656.3$ nm corresponds to a transition between the principal quantum states $n=3$ and $n=2$. The wavelength of the line H_β corresponding to the transition between $n=4$ and $n=2$ is

(a) 486.1nm (b) 886.0 nm (c) 437.5 nm (d) 1093.7 nm

ANSWER KEY

1. (c) 2. (a) 3. (c) 4. (b) 5. (a) 6. (a) 7. (b)
8. (d) 9. (d) 10. (a) 11. (b) 12. (b) 13. (a) 14. (b)
15. (d) 16. (a) 17. (b) 18. (c) 19. (c) 20. (b) 21. (a)
22. (a) 23. (c) 24. (d) 25. (d) 26. (a) 27. (c) 28. (d)
29. (a) 30. (a) 31. (b) 32. (c) 33. (d) 34. (b) 35. (d)
36. (a) 37. (d) 38. (b) 39. (b) 40. (a) 41. (c) 42. (246)
43. (d) 44. (d) 45. (d) 46. (1.06) 47. (c) 48. (c) 49. (a)

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Assignment-2 : Atomic Spectra (L-S and J-J Coupling)

1. The two possible orientations of $\vec{S}$ with respect to an external magnetic field $\vec{B}$ along z-axis, are

(a) $\cos^{-1}\left(\pm\frac{1}{\sqrt{2}}\right)$ (b) $\cos^{-1}\left(\pm\frac{1}{\sqrt{3}}\right)$ (c) $\cos^{-1}\left(\pm\frac{1}{3}\right)$ (d) $\cos^{-1}\left(\pm\frac{1}{2}\right)$

2. The magnitude of magnetic dipole moment corresponding to spin of an electron is

(a) μ_B (b) $2\mu_B$ (c) $\sqrt{2}\mu_B$ (d) $\sqrt{3}\mu_B$

3. A beam of electrons (each of rest mass m, charge e) enters in a uniform magnetic field B along z-axis. The energy separation between the electrons having spin parallel and anti-parallel with magnetic field, is

(a) $\frac{eB\hbar}{m}$ (b) $\frac{eB\hbar}{2m}$ (c) $\frac{eB\hbar}{4m}$ (d) 0

4. The number of possible spectroscopic terms of a one electron atom corresponding to n = 4 is

(a) 3 (b) 5 (c) 7 (d) 9

5. The angle between the orbital angular momentum and spin angular momentum for the term $^2D_{3/2}$ is

(a) 45^0 (b) 62^0 (c) 90^0 (d) 135^0

6. Which of the following spectroscopic term is not allowed?

(a) $^2D_{3/2}$ (b) $^2F_{5/2}$ (c) $^2P_{3/2}$ (d) $^2D_{1/2}$

7. Consider the state in which $l = 4,\ s = 1/2$. The orientation of total angular momentum w.r.t z-axis for the state with largest possible j, m_j, is

(a) 25.2^0 (b) 39.8^0 (c) 51.2^0 (d) 74.8^0

8. Which of the following statements is NOT CORRECT?
The difference of spin-orbit correction to energy between the spin-down and spin-up electron in a hydrogen like atom will

(a) increase with increase in atomic number.
(b) decrease with the principal quantum number
(c) increase with principal quantum number
(d) decrease with orbital quantum number

9. The number of allowed transitions in the fine structure of H_α line is

(a) 3 (b) 4 (c) 5 (d) 7

10. Find the gound state term of the following atoms:

(i) $^{14}_{7}N$ (ii) $^{12}_{6}C$ (iii) $^{16}_{8}O$ (iv) $^{24}_{11}Na$ (v) C^* (vi) Na^*

11. The electronic configuration of $_{25}Mn$ atom is $1s^2 2s^2 2p^6 3s^2 3p^6 3d^5 4s^2$.. The ground state term of Mn atom will be

(a) $^6S_{5/2}$ (b) $^6P_{5/2}$ (c) $^1S_0$ (d) $^3P_0$

12. The ground state term of Mn^{3+} ion will be

(a) $^5D_0$ (b) $^5D_4$ (c) $^6S_{5/2}$ (d) $^6P_{5/2}$

13. If the doublet splitting of the first excited state $2^2D_{5/2} - 2^2D_{3/2}$ of He^+ is 3.67 cm^{-1}, then the corresponding separation of H atom is
(a) 0.23 cm^{-1} (b) 0.36 cm^{-1} (c) 0.52 cm^{-1} (d) 0.76 cm^{-1}

14. Sodium atom has 11 electrons. If the sequence in which the energy levels are filled in 1s, 2s, 2p, 3s, 3p, 4s, 3d...., the ground state of sodium is:
(a) $^3P_{1/2}$ (b) $^2P_{1/2}$ (c) $^1P_{1/2}$ (d) $^2S_{1/2}$

15. There are four electrons in the 3d shell of an isolated atom. The total magnetic moment of the atom in units of Bohr magneton is ______________. **[GATE 2016]**

16. The number of spectroscopic terms resulting from the L.S. coupling of a 3p electron and a 3d electron is __________ **[GATE 2016]**

17. The orbital quantum numbers of two atomic electrons are $\ell_1 = 1$ and $\ell_2 = 2$. The possible values of the total angular momentum quamtum number J under LS coupling are
(a) −1, 1 only (b) 1, 2, 3 only (c) 0, 1, 2, 3, 4 (d) −2, −1, 0, 1, 2

18. Which of the following states exist?
(a) $2\,^2P_1$ (b) $2\,^2P_{3/2}$ (c) $2\,^2P_{5/2}$ (d) $2\,^2P_{7/2}$

19. Under the LS coupling scheme, the possible spectral terms $^{2s+1}L_J$ for the electronic configuration 2s3s are
(a) $^2S_{1/2}, ^2P_{3/2}, ^2P_{1/2}$ (b) $^1S_0, ^3P_1$ (c) $^1S_0, ^3S_1$ (d) $^3S_0, ^3S_1$

20. Which of the following is the spectroscopic ground state for Mn^{3+} ions of electronic configuration $1s^2 2s^2 2p^6 3s^2 3p^6 3d^4$ predicted by Hund's rule?
(a) $^5D_0$ (b) $^5D_4$ (c) $^5D_3$ (d) $^5D_2$

21. Possible values of the total angular momentum quantum number of a single f-electron are
(a) $j = \frac{7}{2}, \frac{5}{2}$ (b) $j = \pm 3, 2, 1, 0$ (c) $j = \pm\frac{7}{2}, \pm\frac{5}{2}$ (d) None of these

22. The electronic configuration (np)^2 can have only which one of the following term
(a) $^2D, ^3P$ or ^1S (b) $^1D, ^3P$ or ^1S (c) $^3D, ^3P$ or ^2S (d) None of these

23. Which of the following has the order of increasing energy?
(a) $^1D_2, ^3D_2, ^3F_2$ (b) $^3F_2, ^3D_2, ^1D_2$ (c) $^3D_2, ^3F_2, ^1D_2$ (d) $^1D_2, ^3F_2, ^3D_2$

24. The electronic configuration of the ground state of the Na atom is $^2S_{1/2}$. This implies that
(a) $S = 2,\ L = 0, J = 2$
(b) $S = 0, L = 1/2,\ J = 1/2$
(c) $S = 1/2,\ L = 0,\ J = 1/2$
(d) $S = 0, L = 2, J = 2$

25. The term symbol for a particular atomic state is $^4P_{5/2}$. The values of S (spin angular momentum), L (orbital angular momentum), J (total angular momentum) of the state are
(a) $S = \frac{3}{2}, L = 0, J = \frac{3}{2}$
(b) $S = \frac{1}{2}, L = 1, J = \frac{3}{2}$
(c) $S = \frac{1}{2}, L = 2, J = \frac{5}{2}$
(d) $S = \frac{3}{2}, L = 1, J = \frac{5}{2}$

26. The spin-orbit interaction in an atom is given by $H = a\vec{L}.\vec{S}$, where $\vec{L}$ and $\vec{S}$ denote the orbital and spin angular momenta respectively, of the electron. The splitting between the levels $^2P_{3/2}$ and $^2P_{1/2}$ is
(a) $\frac{3}{2}a\hbar^2$ (b) $\frac{1}{2}a\hbar^2$ (c) $3a\hbar^2$ (d) $\frac{5}{2}a\hbar^2$ **[NET June 2012]**

27. How does the total angular quantum number J change in the transition $Cr\left(3d^6\right)$ atom ionizes to $Cr^{2+}\left(3d^4\right)$? **[NET June 2014]**
(a) Increases by 2 (b) Decreases by 2 (c) Decreases by 4 (d) Does not change

28. The Lande g-factor for the $^3P_1$ level of an atom is: **[GATE 2001]**
(a) 1/2 (b) 3/2 (c) 5/2 (d) 7/2

29. The spin-orbit coupling constant for the upper state of sodium atom which emits D lines of wave numbers 16956.2 and 16973.4 cm^{-1} is : **[GATE 2003]**
(a) 15 cm^{-1} (b) 11.4 cm^{-1} (c) 12.5 cm^{-1} (d) 15.1 cm^{-1}

30. The spectral term for the atom with 70% subshell and only s =3/2 is **[GATE 2003]**
(a) $^3P_0$ (b) $^4F_{9/2}$ (c) $^3F_{1/2}$ (d) $^4P_{1/2}$

31. The spectral terms for a certain electronic configuration are given by $^3D, {}^1D, {}^3P, {}^1P, {}^5S, {}^3S$. The term with the lowest energy is: **[GATE 2004]**
(a) ^5S (b) ^3P (c) ^3D (d) ^3S

32. The degeneracy of the spectral term ^3F is: **[GATE 2004]**
(a) 7 (b) 9 (c) 15 (d) 21

33. The Lande g factor for the level $^3D_3$ is: **[GATE 2004]**
(a) $\frac{2}{3}$ (b) $\frac{3}{2}$ (c) $\frac{3}{4}$ (d) $\frac{4}{3}$

34. The L, S and J quantum numbers corresponding to the ground state electronic configuration of Boron(Z= 5) are **[GATE 2004]**
(a) $L = 1, S = \frac{1}{2}, J = \frac{3}{2}$ (b) $L = 1, S = \frac{1}{2}, J = \frac{1}{2}$
(c) $L = 1, S = \frac{3}{2}, J = \frac{1}{2}$ (d) $L = 0, S = \frac{3}{2}, J = \frac{3}{2}$

35. The LS configurations of the ground state of ^{12}Mg, ^{13}Al, ^{17}Cl and ^{18}Ar are, respectively.
(a) $^3S_1, {}^2P_{1/2}, {}^2P_{1/2}$ and $^1S_0$ (b) $^3S_1, {}^2P_{3/2}, {}^2P_{3/2}$ and $^3S_1$ **[NET Dec. 2015]**
(c) $^1S_0, {}^2P_{1/2}, {}^2P_{3/2}$ and $^1S_0$ (d) $^1S_0, {}^2P_{3/2}, {}^2P_{1/2}$ and $^3S_1$

36. The degeneracies of the J-states arising from the ^3P term with spin-orbit inteaction are **[GATE 2004]**
(a) 1, 3, 5 (b) 1, 2, 3 (c) 3, 5, 7 (d) 2, 6, 10

37. Deuteron in its ground state has a total angular momentum J = 1 and a positive parity. The corresponding orbital angular momentum L and spin S combinations are **[GATE 2004]**
(a) L = 0, S = 1 and L = 2, S = 0 (b) L = 0, S = 1 and L = 1, S = 1
(c) L = 0, S = 1 and L = 2, S = 1 (d) L = 1, S = 1 and L = 2, S = 1

38. For an electron in hydrogen atom, the states are characterized by the usual quantum numbers n, l, m_l. The electric dipole transition between any two states requires that **[GATE 2005]**
(a) $\Delta\ell = 0, \Delta m_\ell = 0, \pm 1$ (b) $\Delta\ell = \pm 1, \Delta m_\ell = \pm 1, \pm 2$
(c) $\Delta\ell = \pm 1, \Delta m_\ell = 0, \pm 1$ (d) $\Delta\ell = \pm 1, \Delta m_\ell = 0, \pm 2$

39. In a two electron atomic system having orbital and spin angular momenta ℓ_1, ℓ_2 and s_1 s_2 respectively, the coupling strengths are defined as $\Gamma_{\ell_1\ell_2}, \Gamma_{s_1s_2}, \Gamma_{\ell_1s_1}, \Gamma_{\ell_2s_2}, \Gamma_{\ell_1s_2}$ and $\Gamma_{\ell_2s_1}$. For the J-J coupling scheme to be applicable, the coupling strengths MUST satisty the condition. **[GATE 2005]**

(a) $\Gamma_{\ell_1\ell_2}, \Gamma_{s_1s_2} > \Gamma_{\ell_1s_1}, \Gamma_{\ell_2s_2}$
(b) $\Gamma_{\ell_1s_1}, \Gamma_{l_2s_2} > \Gamma_{\ell_1\ell_2}, \Gamma_{s_1s_2}$
(c) $\Gamma_{\ell_1s_2}, \Gamma_{\ell_2s_1} > \Gamma_{\ell_1\ell_2}, \Gamma_{s_1s_2}$
(d) $\Gamma_{\ell_1s_2}, \Gamma_{\ell_2s_1} > \Gamma_{\ell_1s_1}, \Gamma_{s_2s_2}$

40. The allowed states for He($2p^2$) configuration are **[GATE 2007]**

(a) ${}^1S_0$, ${}^3S_1$, ${}^1P_1$, ${}^3P_{0,1,2}$ ${}^1D_2$ and ${}^3D_{1,2,3}$
(b) ${}^1S_0$, ${}^3P_{0,1,2}$ and ${}^1D_2$
(c) ${}^1P_1$ and ${}^3P_{0,1,2}$
(d) ${}^1S_0$ and ${}^1P_1$

41. In accordance with the selection rules of electric dipole transitions, the 4^3P_1 state of helium can decay by photon emission to the states **[GATE 2007]**

(a) $2^1S_0, 2^1P_1$ and 3^1D_2
(b) $3^1P_1, 3^1D_2$ and 3^1S_0
(c) $3^3P_2, 3^3D_3$ and 3^3P_0
(d) $2^3S_1, 3^3D_2$ and 3^3D_1

42. If an atom is in the ${}^3D_3$ state, the angle between its orbital and spin angular momentum vectors $(\vec{L} \text{ and } \vec{S})$ is: **[GATE 2007]**

(a) $\cos^{-1}\dfrac{1}{\sqrt{3}}$
(b) $\cos^{-1}\dfrac{2}{\sqrt{3}}$
(c) $\cos^{-1}\dfrac{1}{2}$
(d) $\cos^{-1}\dfrac{\sqrt{3}}{2}$

43. The last two terms of the electronic configuration of manganese(Mn) atom is $3d^5 4s^2$. The term factor of Mn^{4+} ion is : **[GATE 2008]**

(a) ${}^4D_{1/2}$
(b) ${}^4F_{3/2}$
(c) ${}^3F_{9/2}$
(d) ${}^3D_{7/2}$

44. For a multi-electron atom, ℓ, L and S specify the one-electron orbital angular momentum, total orbital angular momentum and total spin angular momentum, respectively. The selection rules for electric dipole transition between the two electronic energy levels, specified by ℓ, L and S are **[GATE 2011]**

(a) $\Delta L = 0, \pm 1; \Delta S = 0; \Delta\ell = 0, \pm 1$
(b) $\Delta L = 0, \pm 1; \Delta S = 0; \Delta\ell = \pm 1$
(c) $\Delta L = 0, \pm 1; \Delta S = \pm 1; \Delta\ell = 0, \pm 1$
(d) $\Delta L = 0, \pm 1; \Delta S = \pm 1; \Delta\ell = \pm 1$

45. The terms $\{j_1, j_2\}$, arising from $2s^1\ 3d^1$ electronic configuration in $j - j$ coupling scheme are **[GATE 2012]**

(a) $\left\{\frac{1}{2}, \frac{3}{2}\right\}_{2,1}$ and $\left\{\frac{1}{2}, \frac{5}{2}\right\}_{3,2}$
(b) $\left\{\frac{1}{2}, \frac{1}{2}\right\}_{1,0}$ and $\left\{\frac{1}{2}, \frac{3}{2}\right\}_{2,1}$
(c) $\left\{\frac{1}{2}, \frac{1}{2}\right\}_{1,0}$ and $\left\{\frac{1}{2}, \frac{5}{2}\right\}_{3,2}$
(d) $\left\{\frac{3}{2}, \frac{1}{2}\right\}_{2,1}$ and $\left\{\frac{1}{2}, \frac{5}{2}\right\}_{3,2}$

46. The energy difference between the $3p$ and $3s$ levels in Na is 2.1 eV. Spin-orbit coupling splits the $3p$ level, resulting in two emission lines differing by 6 Å. The splitting of the $3p$ level is approximately, **[JEST 2015]**

(a) 2 eV
(b) 0.2 eV
(c) 0.02 eV
(d) 2 meV

47. Which of the following statements is true for the energies of the terms of the carbon atom in the ground state electronic configuration $1s^2 2s^2 2p^2$? **[JEST 2015]**

(a) ${}^3P < {}^1D < {}^1S$
(b) ${}^3P < {}^1S < {}^1D$
(c) ${}^3P < {}^1F < {}^1S$
(d) ${}^3P < {}^1F < {}^1D$

48. In the ground state electronic configuration of nitrogen $\left({}^{14}_{7}\mathrm{N}\right)$ the L, S and J quantum numbers are

[TIFR 2015]

(a) $L=1,\ S=\frac{1}{2},\ J=\frac{1}{2}$ (b) $L=1,\ S=\frac{1}{2},\ J=\frac{3}{2}$

(c) $L=0,\ S=\frac{1}{2},\ J=\frac{1}{2}$ (d) $L=0,\ S=\frac{3}{2},\ J=\frac{3}{2}$

49. If an atom is in the ${}^3D_3$ state, the angle between its orbital and spin angular momentum vectors $\left(\vec{L} \text{ and } \vec{S}\right)$ is

(a) $\cos^{-1}\frac{1}{\sqrt{3}}$ (b) $\cos^{-1}\frac{2}{\sqrt{3}}$ (c) $\cos^{-1}\frac{1}{2}$ (d) $\cos^{-1}\frac{\sqrt{3}}{2}$

50. The Helium atom is excited into the 1s 2s configuration. The following spectral terns ${}^{2s+1}L$ are the only ones allowed

(a) ${}^1S, {}^1P$ (b) ${}^1S, {}^3P$ (c) ${}^1S, {}^3S$ (d) ${}^2S, {}^2P$

51. The possible values of the total angular momentum J resulting from the addition of two angular momenta $J_1 =$ 1 and $J_2 = 2$ are

(a) 1, 2 (b) 1, 3 (c) 0, 1, 2 (d) 1, 2, 3

52. In a hydrogen atom, the accidental or Coulomb degeneracy for the $n = 4$ state is:

(a) 4 (b) 16 (c) 18 (d) 32

53. One Bohr magneton is approximately

(a) $10^{23}\ \mathrm{Am}^2$ (b) $10^{-23}\ \mathrm{Am}^2$ (c) $10^{10}\ \mathrm{Am}^2$ (d) $10^{-10}\ \mathrm{Am}^2$

54. The magnetic moment associated with the first orbit in hydrogen atom is given by

(a) $\frac{h}{4\pi me}$ (b) $\frac{4\pi me}{he}$ (c) $\frac{eh}{4\pi m}\times\sqrt{3}$ (d) $\frac{ehm}{4\pi}$

55. The terms $\{j_1, j_2\}$, arising from $2s^1\ 3d^1$ electronic configuration in $j-j$ coupling scheme are

(a) $\left\{\frac{1}{2},\frac{3}{2}\right\}_{2,1}$ and $\left\{\frac{1}{2},\frac{5}{2}\right\}_{3,2}$ (b) $\left\{\frac{1}{2},\frac{1}{2}\right\}_{1,0}$ and $\left\{\frac{1}{2},\frac{3}{2}\right\}_{2,1}$

(c) $\left\{\frac{1}{2},\frac{1}{2}\right\}_{1,0}$ and $\left\{\frac{1}{2},\frac{5}{2}\right\}_{3,2}$ (d) $\left\{\frac{3}{2},\frac{1}{2}\right\}_{2,1}$ and $\left\{\frac{1}{2},\frac{5}{2}\right\}_{3,2}$

56. The spatial part of a two-electron state is symmetric under exchange. If $|\uparrow\rangle$ and $|\downarrow\rangle$ represent the spin-up and spin-down states respectively of each particle, the spin-part of the two-particle state is

(a) $|\uparrow\rangle|\uparrow\rangle$ (b) $|\uparrow\rangle|\downarrow\rangle$ (c) $|\downarrow\rangle|\uparrow\rangle-|\uparrow\rangle|\downarrow\rangle/\sqrt{2}$ (d) $|\downarrow\rangle|\uparrow\rangle+|\uparrow\rangle|\downarrow\rangle/\sqrt{2}$

57. The ground state electronic configuration for a carbon atom is $(1s)^2(2s)^2(2p)^2$

The first excited state of this atom would be achieved by

(a) re-alignment of the electron spins within the 2p orbital

(b) transition of an electron from the 2s orbital to the 2p orbital.

(c) transition of an electron from the 2p orbital to the 3s orbital

(d) transition of an electron from 2s orbital to the 3s orbital.

58. In the ground state electronic configuration of nitrogen $\left({}^{14}_{7}\mathrm{N}\right)$ the L, S and J quantum numbers are

[TIFR 2015]

(a) $L=1,\ S=\frac{1}{2},\ J=\frac{1}{2}$ (b) $L=1,\ S=\frac{1}{2},\ J=\frac{3}{2}$

(c) $L=0,\ S=\frac{1}{2},\ J=\frac{1}{2}$ (d) $L=0,\ S=\frac{3}{2},\ J=\frac{3}{2}$

59. Which of the following statements is true for the energies of the terms of the carbon atom in the ground state electronic configuration $1s^2 2s^2 2p^2$? [JEST 2015]

(a) ${}^3P < {}^1D < {}^1S$ (b) ${}^3P < {}^1S < {}^1D$ (c) ${}^3P < {}^1F < {}^1S$ (d) ${}^3P < {}^1F < {}^1D$

60. Of the following term symbols of the np^2 atomic configurations, ${}^1S_0$, ${}^3P_0$, ${}^3P_1$, ${}^3P_2$ and ${}^1D_2$ which is the grounded state ? [NET June 2015]

(a) ${}^3P_0$ (b) ${}^1S_0$ (c) ${}^3P_2$ (d) ${}^3P_1$

61. In the L-S coupling scheme, the terms arising from two non-equivalent p-electrons are [NET Dec. 2016]

(a) ${}^3S, {}^1P, {}^3P, {}^1D, {}^3D$ (b) ${}^1S, {}^3S, {}^1P, {}^1D$

(c) ${}^1S, {}^3S, {}^3P, {}^3D$ (d) ${}^1S, {}^3S, {}^1P, {}^3P, {}^1D, {}^3D$

62. Using Hund's rule, the total angular momentum quantum number J for the electronic ground state of the nitrogen atom is [GATE 2017]

(a) 1/2 (b) 3/2 (c) 0 (d) 1

63. The term symbol for the electronic ground state of oxygen atom is [GATE 2018]

(a) ${}^1S_0$ (b) ${}^1D_2$ (c) ${}^3P_0$ (d) ${}^3P_2$

64. The separations between the adjacent levels of a normal multiplet are found to be 22 cm^{-1} and 33 cm^{-1}. Assume that the multiplet is described well by the L-S coupling scheme and the Lande's interval rule, namely $E(J)-E(J-1)=AJ$, where A is a constant. The term notations for this multiplet is

(a) ${}^3P_{0,1,2}$ (b) ${}^3F_{2,3,4}$ (c) ${}^3G_{3,4,5}$ (d) ${}^3D_{1,2,3}$ [NET Dec. 2017]

ANSWER KEY

1. (b)	**2. (d)**	**3. (a)**	**4. (c)**	**5. (d)**	**6. (d)**	**7. (a)**
8. (c)	**9. (7)**	**10. (*)**	**11. (a)**	**12. (a)**	**13. (a)**	**14. (d)**
15. (0)	**16. (12)**	**17. (c)**	**18. (b)**	**19. (c)**	**20. (a)**	**21. (a)**
22. (b)	**23. (b)**	**24. (c)**	**25. (d)**	**26. (a)**	**27. (c)**	**28. (b)**
29. (b)	**30. (b)**	**31. (a)**	**32. (d)**	**33. (d)**	**34. (b)**	**35. (c)**
36. (a)	**37. (c)**	**38. (c)**	**39. (b)**	**40. (b)**	**41. (d)**	**42. (a)**
43. (b)	**44. (b)**	**45. (a)**	**46. (d)**	**47. (a)**	**48. (d)**	**49. (a)**
50. (c)	**51. (d)**	**52. (b)**	**53. (b)**	**54. (c)**	**55. (a)**	**56. (c)**
57. (a)	**58. (d)**	**59. (a)**	**60. (a)**	**61. (d)**	**62. (b)**	**63. (d)**
64. (d)						

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Assignment-3 : Atomic Spectra (Zeeman Effect)

1. A sample of certain element is placed in a magnetic field $\vec{B}$. The wavelength separation between the Ze components of a spectral line of wavelength λ will be

   (a) $\frac{\mu_B B}{hc}\lambda$ (b) $\frac{\mu_B B}{hc\lambda}$ (c) $\frac{hc\lambda}{\mu_B B}$ (d) $\frac{\mu_B B}{hc}\lambda^2$

2. In the presence of external weak magnetic field, the number of substates into which the state ${}^2D_{5/2}$ will spl

   (a) 3 (b) 4 (c) 5 (d) 6

3. In the presence of weak magnetic field B, the separation between the splitted sublevels of the ${}^3D_2$ level will b

   (a) $\frac{7eB}{24\pi mc}$ (b) $\frac{7eB}{12\pi mc}$ (c) $\frac{7eB}{6\pi mc}$ (d) none of these

4. The number of Zeeman components for ${}^2D_{3/2} - {}^2P_{3/2}$ transition in one-electron atom will be

   (a) 6 (b) 8 (c) 10 (d) 12

5. The Zeeman pattern of a line consists of six equidistant components. The upper state term is known to be ${}^2P_{3/2}$. The lower state term will be

   (a) ${}^1P_1$ (b) ${}^2S_{1/2}$ (c) ${}^1S_0$ (d) none of these

6. The sodium doublet lines are due to transitions from ${}^2P_{3/2}$ and ${}^2P_{1/2}$ levels to ${}^2S_{1/2}$ level. On application of a weak magnetic field, the total number of the allowed transitons are

   (a) 4 (b) 6 (c) 8 (d) 10

7. The spectroscopic symbol for the ground state of ${}_{13}$Al is ${}^2P_{1/2}$. Under the action of a strong magnetic field (when L-S coupling can be neglected) the ground state energy level will split into **[NET Dec. 2013]**

   (a) 3 levels (b) 4 levels (c) 5 levels (d) 6 levels

8. A spectral line due to a transition from an electronic state p to an s state splits into three Zeeman lines in the presence of a strong magnetic field. At intermediate field strengths the number of spectral lines is **[NET June 2014]**

   (a) 10 (b) 3 (c) 6 (d) 9

9. An atomic transition ${}^1P \rightarrow {}^1S$ in a magnetic field 1 Tesla shows Zeeman splitting. Given that the Bohr magneton $\mu_B = 9.27 \times 10^{-24}$ J/T, and the wavelength corresponding to the transition is 250 nm, the separation in the Zeeman spectral lines is approximately **[NET Dec. 2014]**

   (a) 0.01 nm (b) 0.1 nm (c) 1.0 nm (d) 10 nm

10. The total number of Zeeman components observed in an electronic transition ${}^2D_{5/2} \rightarrow {}^2P_{3/2}$ of an atom in a weak field is: **[GATE 2001]**

   (a) 4 (b) 6 (c) 12 (d) 10

Common data for Q.11 and Q.12

In the presence of an inhomogeneous weak magnetic field, spectral lines due to transitions between two sets of states were observed.

$$(1)\ {}^5I_5 \to {}^5H_4 \text{ and } (2)\ {}^2D_{5/2} \to {}^2P_{3/2}$$ **[GATE 2003]**

11. The types of Zeeman effect observed in (1) and (2) respectively are

(a) normal, normal
(b) anomalous, anomalous
(c) anomalous, normal
(d) normal, anomalous

12. The number of levels into which each of the above four terms split into respectively is:

(a) 6, 4, 10, 8
(b) 4, 6, 10, 12
(c) 11, 9, 6, 4
(d) 9, 5, 12, 10

13. The D_1 and D_2 lines of Na atom will split on the application of a weak magnetic field into

(a) 4 and 6 lines
(b) 3 lines each
(c) 6 and 4 lines
(d) 6 lines each

Common Data Q. 14 and Q.15

Consider the Zeeman splitting of a single electron system for the $3d \to 3p$ electric dipole transition.

14. The Zeeman spectrum is : **[GATE 2009]**

(a) Randomly polarized
(b) Only π polarized
(c) Only σ polarized
(d) Both π and σ polarized

15. The fine structure line having the longest wavelength will split into :

(a) 17 components
(b) 10 components
(c) 8 components
(d) 4 components

Common Data for Q.16 and Q. 17

In the presence of a weak magnetic field, atomic hydrogen undergoes the transition:

$$^2p_{1/2} \to {}^2s_{1/2}$$

by emission of radiation. **[GATE 2010]**

16. The number of distinct spectral lines that are observed in the resultant Zeeman spectrum is

(a) 2
(b) 3
(c) 4
(d) 6

17. The spectral line corresponding to the transition

$$^2P_{1/2}\left(m_j = +\frac{1}{2}\right) \to {}^2S_{1/2}\left(m_j = -\frac{1}{2}\right)$$

is observed along the direction of the applied magnetic field. The emitted electromagnetic field is:

(a) Circularly polarized
(b)Linearly polarized
(c) Unpolarized
(d) Not emitted along the magnetic field direction

18. An atom with one outer electron having orbital angular momentum l is placed in a weak magnetic field. The number of energy levels into which the higher total angular momentum state splits, is **[GATE 2011]**

(a) $2\ell+2$
(b) $2\ell+1$
(c) 2ℓ
(d) $2\ell-1$

19. In a normal Zeeman effect experiment, spectral splitting of the line at the wavelength 643.8 nm corresponding to the transition $5\,{}^1D_2 \to 5\,{}^1P_1$ of cadmium atom is to be observed. The spectrometer has a resolution of 0.01 nM. The minimum magnetic field needed to observe this is ($m_e = 9.1\times10^{-31}$ *kg*, $e = 1.6\times10^{-19}$ *C*, $c = 3\times10^{8}$ *m/s*) **[GATE 2013]**

(a) 0.26 T
(b) 0.52 T
(c) 2.6 T
(d) 5.2 T

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20. When a pure element is vaporised and placed in a uniform magnetic field B_0, it is seen that a particular spectral line of wavelength l, corresponding to a J = 1 ® J = 0 transition, gets split into three components $\lambda, \lambda \pm \Delta\lambda$. It follows that the Lande g-factor for the transition J = 1 ® = 0 is given by **[TIFR 2013]**

(a) $g = \frac{hc}{\mu_B B_0}\frac{\Delta\lambda^2}{\lambda}$ (b) $g = \frac{hc}{\mu_B B_0}\frac{\lambda^2}{\Delta\lambda}$ (c) $g = \frac{hc}{\mu_B B_0}\frac{\lambda}{\Delta\lambda^2}$ (d) $g = \frac{hc}{\mu_B B_0}\frac{\Delta\lambda}{\lambda^2}$

21. The D1 and D2 lines of Na$\left(3^2P_{1/2} \rightarrow 3^2S_{1/2}, 3^2P_{3/2} \rightarrow 3^2S_{1/2}\right)$ will split on the application of a weak magnetic field into

(a) 4 and 6 lines respectively
(b) 3 lines each
(c) 6 and 4 lines respectively
(d) 6 lines each

22. In Zeeman effect, a spectral-line, upon the application of magnetic field, splits into more than three componets because of

(a) Energy levels split into 2J + 1
(b) In magnetic field $\Delta m_J = 0, \pm 1$ no longer holds
(c) Variation of Lande g-factor from one level to another
(d) None of the above

23. In the Zeeman effect the light emitted along and perpendicular to the applied magnetic field are respectively

(a) linearly and circularly polarized
(b) circularly and linearly polarized
(c) both linearly polarized
(d) both circularly polarized

24. In a normal Zeeman effect experiment using a magnetic field of strength 0.3 T, the splitting between the components of a 660 nm spectral line is **[NET June 2016]**

(a) 12 pm (b) 10 pm (c) 8 pm (d) 6 pm

25. An atomic spectral line is observed to split into nine components due to Zeeman shift. If the upper state of the atom is $^3D_2$ then the lower state will be **[NET June 2017]**

(a) $^3F_2$ (b) $^3F_1$ (c) $^3P_1$ (d) $^3P_2$

26. Which one of the following is an allowed electric dipole transition ? **[GATE 2018]**

(a) $^1S_0 \rightarrow {}^3S_1$ (b) $^2P_{3/2} \rightarrow {}^2D_{5/2}$ (c) $^2D_{5/2} \rightarrow {}^2P_{1/2}$ (d) $^3P_0 \rightarrow {}^5D_0$

27. Given the following table, **[GATE 2018]**

Group-I	**Group-II**
P. Stem-Gerlach experiment	**1.** Wave nature of particles
Q. Zeeman effect	**2.** Quantization of energy of electrons in the atoms
R. Frank-Hertz experiment	**3.** Existence of electron spin
S. Davisson-Germer experiment	**4.** Space quantization of angular momentum

Which one of the following correctly matches the experiments from Group-I to their inferences in Group-II ?

(a) P-2, Q-3, R-4, S-1
(b) P-1, Q-3, R-2, S-4
(c) P-3, Q-4, R-2, S-1
(d) P-2, Q-1, R-4, S-3

28. An atom in its single state is subjected to a magnetic field. The Zeeman splitting of its 650 nm spectral lines is 0.03 nm. The magnitude of the field is ________ Tesla (up to two decimal places).

$$\left[e = 1.60\times10^{-19}\,\text{C},\ m_e = 9.11\times10^{-31}\,\text{kg},\ c = 3.0\times10^{8}\,\text{ms}^{-1}\right]$$

[GATE 2018]

29. The Zeeman shift of the energy of a state with quantum numbers L, S, J and m_J is **[NET Dec. 2017]**

$$H_Z = \frac{m_J \mu_B B}{J(J+1)}\left(\langle L\cdot J\rangle + g_S\langle S\cdot J\rangle\right)$$

where B is the applied magnetic field, g_S is the g-factor for the spin and $\mu_B/h = 1.4$ MHz-G^{-1}, where h is the Planck constant. The approximate frequency shift of the $S=0,\ L=1$ and $m_J=1$ state, at a magnetic field of 1 G, is

(a) 10 MHz [✓ (b) 1.4 MHz] (c) 5 MHz (d) 2.8 MHz

30. The ground state of sodium atom $\left({}^{11}\text{Na}\right)$ is a ${}^2S_{1/2}$ state. The difference in energy levels arising in the presence of a weak external magnetic field B, given in terms of Bohr magneton, μ_B, is

(a) $\mu_B B$ (b) $2\mu_B B$ (c) $4\mu_B B$ (d) $6\mu_B B$

31. The value of the Lande g-factor for a fine structure level defined by the quantum numbers L = 1 and J = 2 and S = 1, is **[NET June 2018]**

(a) 11/6 (b) 4/3 (c) 8/3 (d) 3/2

ANSWER KEY

1. (d)	**2. (d)**	**3. (a)**	**4. (c)**	**5. (b)**	**6. (d)**	**7. (c)**
8. (a)	**9. (a)**	**10. (c)**	**11. (b)**	**12. (c)**	**13. (a)**	**14. (d)**
15. (b)	**16. (c)**	**17. (a)**	**18. (a)**	**19. (b)**	**20. (d)**	**21. (a)**
22. (c)	**23. (c)**	**24. (d)**	**25. (c)**	**26. (b)**	**27. (c)**	**28. (1.52)**
29. (b)	**30. (b)**	**31. (d)**				

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Assignment-4 : Atomic Spectra (X-ray Spectra, Alkalic Spectra, Hyperfine Structure & Broadening)

1. The number of components in the hyperfine structure corresponding to the spectral line due to the transition $^2D_{3/2} \to ^2P_{1/2}$ within a certain atom (having nuclear spin I = 9/2), is

(a) 4 (b) 6 (c) 8 (d) 10

Common Data for Q.2 and Q.3

A certain atom has a excited state $^2D_{5/2}$, which splits into six hyperfine levels. The distance between the two consecutive hyperfine levels are 0.236 cm^{-1}, 0.312 cm^{-1}, 0.391 cm^{-1}, 0.471 cm^{-1}, 0.551 cm^{-1} respectively.

2. The nuclear spin quantum number of the atom is

(a) 1/2 (b) 3/2 (c) 7/2 (d) 9/2

3. The hyperfine structure constant of the molecule is

(a) 0.039 cm^{-1} (b) 0.078 cm^{-1} (c) 0.098 cm^{-1} (d) 0.112 cm^{-1}

4. The number of hyperfine components observed in the electronic transition $^2p_{1/2} \to ^2S_{1/2}$ of an atom with nuclear spin 1/2 is :

(a) 3 (b) 4 (c) 6 (d) 5

5. The hyperfine splitting of the spectral lines of an atom is due to :

(a) The coupling between the spins of two or more electron

(b) The coupling between the spins and the orbital angular momenta of the electron

(c) The coupling between the electron spins and the nuclear spin

(d) The effect of external electromagnetic field

6. The hyperfine structure of $Na\left(3^2P_{3/2}\right)$ with nuclear spin I = 3/2 has

(a) 1 state (b) 2 states (c) 3 states (d) 4 states

7. In hyperfine interaction, there is coupling between the electron angular momentum $\vec{J}$ and nuclear angular momentum $\vec{I}$, forming resultant angular momentum $\vec{F}$. The selection rules for the corresponding quantum number F in hyperfine transitions are

(a) $\Delta F = \pm 2$ only (b) $\Delta F = \pm 1$ only (c) $\Delta F = 0, \pm 1$ (d) $\Delta F = \pm 1, \pm 2$

8. Cesium has a nuclear spin of 7/2. The hyperfine spectrum of the D lines of the Cesium atom will consist of

(a) 10 lines (b) 4 lines (c) 6 lines (d) 14 lines

9. The wavelength of a photon emiited from a moving source is appeared to be 500.1 nm, whereas the actual wavelength is 500 nm. The speed and direction of the movement of the source w.r.t the observer is

(a) 30 km/sec, away from the observer (b) 60 km/sec, away from the observer

(c) 30 km/sec, towards the observer (d) 60 km/sec, towards the observer

10. The dependence of Doppler broadened line width of a laser transition on temperature T is given by

(a) T (b) $T^{-1/2}$ (c) $T^{1/2}$ (d) T^2

11. The minimum voltage that must be applied to a X-ray tube to produce X-ray photons of wavelength 0.01 nm, is

(a) 50 KV (b) 75 KV (c) 100 KV (d) 125 KV

12. If the wavelength limit of the K-series for a certain element is about 0.1 nm, then the atomic number of the element will be

(a) 19 (b) 25 (c) 31 (d) 39

13. The Copper (Z = 29) target in an X-ray tube has some impurity in it. In the X-ray spectrum emitted from the tube, there is an additional line of wavelength $0.54\ A^0$ alongwith the K_α line of wavelength $1.54\ A^0$. The impurity present in the target of the X-ray tube may be

(a) Na (b) K (c) Cl (d) Cd

14. The continuous X-ray spectrum is the result of the
(a) Photoelectric effect (b) Inverse photoelectric effect
(c) Compton effect (d) Auger effect

15. The energy E of K_αX -rays emitted from targets of different atomic number Z varies as
(a) Z^2 (b) $Z^{2/3}$ (c) Z (d) $Z^{1/2}$

16. Which one of the following would not cause the broadening in spectral lines?
(a) Doppler effect (b) Heisenberg's uncertainty
(c) Absorption of e.m. radiation (d) Collisions

17. The linear Stark effect is possible in a hydrogen atom but not in a sodium atom because

(a) The principal quantum number for the ground state of the sodium atom is different from that of the hydrogen atm in the ground state
(b) Spin-orbit interaction is stronger in sodium than in hydrogen
(c) The electronic energy levels of sodium exhibit orbital-degeneracy
(d) The electronic energy levels of hydrogen exhibit orbital-degeneracy

18. The possible values of the total angular momentum J resulting from the addition of two angular momenta $J_1 = 1$ and $J_2 = 2$ are

(a) 1, 2 (b) 1, 3 (c) 0, 1, 2 (d) 1, 2, 3

19. The normal Zeeman effect is:
(a) Observed only in atoms with an even number of electrons
(b) Observed only in atoms with an odd number of electrons
(c) A confirmation of space quantization
(d) Not a confirmation of space quantization

20. In a Stern-Gerlach experiment the atomic beam whose angular momentum state is to be determined, must travel through
(a) Homogeneous radio frequency magnetic field
(b) Homogeneous static magnetic field
(c) Inhomogeneous static magnetic field
(d) Inhomogeneous radio frequency magnetic field

21. The L_β line of X-rays emitted from an atom with principal quantum numbers n = 1, 2, 3, ... arises from the transition.
(a) $n = 4 \rightarrow n = 2$ (b) $n = 3 \rightarrow n = 2$ (c) $n = 5 \rightarrow n = 2$ (d) $n = 3 \rightarrow n = 2$

22. The principal series of spectral lines of lithium is obtained by transitions between

(a) nS and 2P, n > 2 (b) nD and 2P, n > 2
(c) nP and 2S, n > 1 (d) nF and 3D, n > 3

23. In the linear Stark effect, the application of an electric field

(a) completely lifts the degeneracy of n = 2 level on hydrogen atom amd splits n = 2 level into four levels
(b) Partially lifts the degeneracy of n = 2 level on hydrogen atom amd splits n = 2 level into three levels
(c) Partially lifts the degeneracy of n = 2 level on hydrogen atom and splits n = 2 level into two levels
(d) Does not affect the n = 2 levels

24. Group I lists some physical phenomena while Group II gives some physical parameters. Match the phenomena with the corresponding parameter.

Goup I	Group II
P. Doppler Broadening	1. Moment of inertia
Q. Natural Broadening	2. Refractive index
R. Rotational spectrum	3. Lifetime of the energy level
S. Total internal reflection	4. Pressure

(a) P-4, Q-3, R-1, S-2 (b) P-3, Q-2, R-1, S-4
(c) P-2, Q-3, R-4, S-1 (d) P-1, Q-4, r-2, S-3

25. Cesium has a nuclear spin of 7/2. The hyperfine spectrum of the D lines of the Cesium atom will consist of

(a) 10 lines (b) 4 lines (c) 6 lines (d) 14 lines

26. The ratio of intensities of the D_1 and D_2 lines of sodium at high temperature

(a) 1:1 (b) 2:3 (c) 1:3 (d) 1:2

27. As a consequence of the interaction between the electron's orbital angular momentum and the nuclear spin, the $^2S_{1/2}$ electronic level of the hydrogen atom

(a) shifts up by a constant amount (b) splits into two hyperfine levels
(c) shifts down by a constant amount (d) splits into three hyperfine levels

28. The electronic energy levels in a hydrogen atom are given by $E_n = -13.6/n^2$ eV. If a selective excitation to the n = 100 level is to be made using a laser, the maximum allowed frequency line-width of the laser is

(a) 6.5 MHz (b) 6.5 GHz (c) 6.5 Hz (d) 6.5 kHz

29. A continuous monochromatic ($\lambda = 600$ nm) laser beam is chopped into 0.1 ns pulses using some sort of shutter. Find the resultant linewidth $\Delta\lambda$ of the beam in units of 10^{-3} nm. **[JEST 2016]**

30. The total spin of a hydrogen atom is due to the contribution of the spins of the electron and the proton. In the high temperature limit, the ratio of the number of atoms in the spin-1 state to the number in the spin-0 state is **[NET Dec. 2016]**

(a) 2 (b) 3 (c) 1/2 (d) 1/3

31. If the bindings energies of the electron in the K and L shells of silver atom are 25.4 keV and 3.34 keV, respectively, then the kinetic energy of the Auger electron will be approximately **[NET June 2017]**

(a) 22 keV (b) 9.3 keV (c) 10.5 keV (d) 18.7 keV

32. Match the physical effects and order of magnitude of their energy scales given below, where $\alpha = \dfrac{e^2}{4\pi\varepsilon_0 \hbar c}$ is fine structure constant ; m_e and m_p are electron and proton mass, respectively. **[GATE 2018]**

Group-I	**Group-II**
P. Lamb shift	**1.** $\sim O(\alpha^2 m_e c^2)$
Q. Fine structure	**2.** $\sim O(\alpha^4 m_e c^2)$
R. Bohr energy	**3.** $\sim O(\alpha^4 m_e^2 c^2 / m_p)$
S. Hyperfine structure	**4.** $\sim O(\alpha^5 m_e c^2)$

(a) P-3, Q-1, R-2, S-4 (b) P-2, Q-3, R-1, S-4
(c) P-4, Q-2, R-1, S-3 (d) P-2, Q-4, R-1, S-3

33. The intrinsic/permanent electric dipole moment in the ground state of hydrogen atom is (a_0 is the Bohr radius).

(a) $-3ea_0$ (b) zero (c) ea_0 (d) $3ea_0$ **[GATE 2018]**

34. The number of spectral lines allowed in the spectrum for the $3^2D \to 3^2P$ transitions in sodium are ________ **[GATE 2013]**

35. Which of the following transitions give rise to the $K_{\alpha 1}$ line of X-ray spectra?

(a) $2\,^2S_{1/2} \to 1\,^2S_{1/2}$ (b) $2\,^2P_{1/2} \to 1\,^2S_{1/2}$ (c) $2\,^2P_{5/2} \to 1\,^2S_{1/2}$ (d) $2\,^2P_{3/2} \to 1\,^2S_{1/2}$

36. A photon energy 115.62 keV ionizes a K-shell electron of a Be atom. One L-shell electron jumps to the K-shell to fill this vacancy and emits a photon of energy 109.2 keV in the process. If the ionization potential for the L-shell is 6.4 keV, the kinetic energy of the ionized electron is **[NET June 2018]**

(a) 6.42 keV (b) 12.82 keV (c) 20 eV (d) 32 eV

ANSWER KEY

1. (b) **2. (d)** **3. (b)** **4. (a)** **5. (c)** **6. (d)** **7. (c)**

8. (a) **9. (b)** **10. (c)** **11. (d)** **12. (c)** **13. (d)** **14. (b)**

15. (a) **16. (c)** **17. (d)** **18. (d)** **19. (c)** **20. (c)** **21. (a)**

22. (c) **23. (c)** **24. (a)** **25. (a)** **26. (d)** **27. (b)** **28. (c)**

29. (1.91) **30. (b)** **31. (d)** **32. (c)** **33. (b)** **34. (3)** **35. (d)**

36. (c)

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Assignment-5 : Rotational Spectra

1. The $J=0 \rightarrow J=1$ absorption line in CO occurs at a frequency of $1.153\times10^{11}\,s^{-1}$. (Given: The reduced mass of CO molecule is $1.14\times10^{-26}\,kg$). The $J=0 \rightarrow J=1$ transition line occurs at a frequency of $1.153\times10^{11}\,s^{-1}$ in ${}^{12}C^{16}O$ and at a frequency of $1.102\times10^{11}\,s^{-1}$ in ${}^{?}C^{16}O$. The mass number of the unknown isotope of carbon is

(a) 13 (b) 14 (c) 15 (d) 16

Common Data for Q.2, Q.3 and Q.4

The separation of lines in the microwave red spectrum of HCl is 20.68 cm^{-1}.

(Given: The reduced mass of HCl molecule is $1.62\times10^{-27}\,kg$)

2. The $J=14 \rightarrow J=15$ transition occurs at

(a) $103.4\,cm^{-1}$ (b) $206.8\,cm^{-1}$ (c) $310.2\,cm^{-1}$ (d) $413.6\,cm^{-1}$

3. The moment of inertia of the HCl molecule is

(a) $1.34\times10^{-40}\,kg-m^2$ (b) $2.7\times10^{-40}\,kg-m^2$ (c) $1.34\times10^{-47}\,kg-m^2$ (d) $2.7\times10^{-47}\,kg-m^2$

4. The internuclear distance of HCl molecule is

(a) $0.48A^0$ (b) $0.84A^0$ (c) $1.30A^0$ (d) $1.95A^0$

5. The wave numbers (in cm^{-1}) of the lines of a band in the microwave region are given by

$$\nu = 1000(2n-1) \quad \text{for positive } 'n'$$
$$= -1000(2n+1) \quad \text{for negative } 'n'$$

The moment of inertia of the emitter molecule of the spectrum is

(a) $2.8\times10^{-49}\,kg-m^2$ (b) $5.6\times10^{-49}\,kg-m^2$ (c) $8.4\times10^{-49}\,kg-m^2$ (d) $11.2\times10^{-49}\,kg-m^2$

6. Which one of the following molecule does not exhibit rotational spectra?

(a) CCl_4 (b) HF (c) HBr (d) O_2

7. The lines in the microwave sprctrum of ${}^{1}H^{127}I$ are separated by A cm^{-1}. The lines in the microwave spectrum of ${}^{2}H^{127}I$ will be separated by

(a) $\frac{A}{4}$ (b) $\frac{A}{2}$ (c) $\frac{A}{\sqrt{2}}$ (d) A

8. The spacing between the rotational lines of HF molecule is 40 cm^{-1}. The corresponding spacing between rotational lines in DF molecule is approximately

(a) 20 cm^{-1} (b) 30 cm^{-1} (c) 60 cm^{-1} (d) 7.5 cm^{-1}

9. At a given temparature, for a rigid rotator, the probability that the system is in the rotational state J = 0 is 0.6, in state J = 1is 0.3and in state J = 2 is 0.1. The average enegy of the rotator at the given tempararture will be (Given: Rotational constant of the rotator is B)

(a) 6B (b) 1.2 B (c) 3.6 B (d) 4.8 B

10. Consider the CO molecule as a diatomic rigid rotor with a bond length of 1.12 Å. The reduced mass of the system is obtained from the atomic masses of C and O. The rotational energies are defined in terms of B(the rotational constant) and J (the rotational quantum number). If v_1 and v_2 denotes the frequency of the first rotational resonance lines for the moleules $^{12}C\,^{16}O$ and $^{13}C\,^{18}O$ respectively, their ratio v_1/v_2 is approximately.

(a) 1.5 (b) 1.1 (c) 0.9 (d) 1.01

11. In which of the following pairs do both molecules exhibit rotational spectra?

(a) CCl_4 and HF (b) CCl_4 and O_2 (c) HCN and HF (d) HCN and CCl_4

12. The population in the first rotational state of diatomic molecule relative to the lowest state is $3e^{-2}$. The relative population in the second rotational state is

(a) $4e^{-3}$ (b) $5e^{-4}$ (c) $5e^{-6}$ (d) $4e^{-5}$

13. The relative population in two states with energies E_1 and E_2 satisfying Boltzmann distribution is given by

$$\frac{n_1}{n_2}=\frac{3}{2}\exp\left[-\frac{(E_2-E_1)}{k_BT}\right]$$

The relative degenaracy g_2/g_1 is

(a) 2 (b) 2/3 (c) 3/2 (d) 3

14. The equillibrum population ratio (n_f/n_i) of a doubly degenarate level (E_f) lying at energy 2 units higher than a lower non-degenarate energy level (E_i), will be (assuming $k_BT=1$ unit)

(a) $\frac{2}{e^2}$ (b) $\frac{1}{e^2}$ (c) e^2 (d) $2e^2$

15. The population of Jth rotational level is given by

$$N_J=N_0(2J+1)\exp\left[-\frac{BJ(J+1)}{k_BT}\right]$$

where N_0 is the population in the ground state. The J value of the rotational level with maximum population is given by,

(a) $\frac{\left[\frac{2kT}{B}-1\right]}{\sqrt{2}}$ (b) $\frac{\left[\sqrt{\frac{2kT}{B}}-1\right]}{2}$ (c) $\frac{kT}{B}$ (d) $\frac{B}{kT}$

16. Three consecutive lines in the microwave spectrum of HBr molecule are found to be at 84.544 cm^{-1}, 101.355 cm^{-1} and 118.112 cm^{-1} respectively. The rotational constant of the HBr molecule is

(a) 3.7 cm^{-1} (b) 5.2 cm^{-1} (c) 6.9 cm^{-1} (d) 8.5 cm^{-1}

17. The first absorption spectrum of $^{12}C^{16}O$ is at $3.842\,\text{cm}^{-1}$ while that of $^{13}C^{16}O$ is at $3.673\,\text{cm}^{-1}$. The ratio of their moments of inertia is **[NET June 2012]**

(a) 1.851 (b) 1.286 (c) 1.046 (d) 1.038

18. Consider the hydrogen deuterium molecule HD. If the mean distance between the two atoms is 0.08 nm and the mass of the hydrogen atom is 938 MeV/c^2, then the energy difference ΔE between the two lowest rotational states is approximately **[NET June 2013]**

(a) 10^{-1}eV (b) 10^{-2}eV (c) 2×10^{-2}eV (d) 10^{-3}eV

19. Three values of rotational energies of molecules are given below in different units

P: 10 cm^{-1} **Q:** 10^{-23} J **R:** 10^4 MHz

Choose the correct arrangement in the increasing order of energy **[GATE 2003]**

(a) P, Q, R (b) R, Q, P (c) R, P, Q (d) Q, R, P

20. Consider the pure rotational spectrum of a diatomic rigid rotor, The separation between two consecutive lines $(\Delta\bar{V})$ in the spectrum **[GATE 2004]**

(a) Is directly proportional to the moment of inertial of the rotor
(b) In inversely proportional to the moment of inertia of the rotor
(c) Depends on the angular momentum
(d) Is directly proportional to the square of the interatomic separation

21. In the microwave spectrum of identical rigid diatomic molecules, the separation between the spectral lines is recorded to be 0.7143 cm^{-1}. The moment of inertia of the molecule, in kg m^2, is **[GATE 2006]**

(a) 2.3×10^{-36} (b) 2.3×10^{-40} (c) 7.8×10^{-42} (d) 7.8×10^{-46}

22. The allowed rotational energy levels of a rigid hetero-nuclear diatomic molecule are expressed as $\varepsilon_J = BJ(J+1)$, where B is the rotational constant and J is a rotational quantum number.
In a system of such diatomic molecules of reduced mass μ, some of the atoms of one element are replaced by a heavier isotope, such that the reduced mass is changed to 1.05μ. In the rotational spectrum of the system, the shift in the spectral line, corresponding to a transition $J = 4 \rightarrow J = 5$, is **[GATE 2007]**

(a) 0.475B (b) 0.50 B (c) 0.95 B (d) 1.0 B

23. Three consecutive absorption lines at $64.275\ cm^{-1}$, $77.130\ cm^{-1}$ and $89.985\ cm^{-1}$ have been observed in a microwave spectrum for a linear rigid diatomic molecule. The moments of inertia I_A and I_B are (I_A is with respect to the bond axis passing through the centre of mass and I_B is with respect to an axis passing through the centre of mass and perpendicular to bond axis) **[GATE 2008]**

(a) both equal to $\frac{\hbar^2}{12.855hc}\text{gm cm}^2$ (b) zero and $\frac{\hbar^2}{12.855hc}\text{gm cm}^2$

(c) both equal to $\frac{\hbar^2}{6.427hc}\text{gm cm}^2$ (d) zero and $\frac{\hbar^2}{6.427hc}\text{gm cm}^2$

24. The three principal moments of inertia of a methanol (CH_3OH) molecule have the property $I_x = I_y = I$ and $I_z \neq I$. The rotational energy eigenvalues are **[GATE 2010]**

(a) $\frac{\hbar^2}{2I}\ell(\ell+1)+\frac{\hbar^2 m_l^2}{2}\left(\frac{1}{I_z}-\frac{1}{I}\right)$ (b) $\frac{\hbar^2}{2I}\ell(\ell+1)$

(c) $\frac{\hbar^2 m_l^2}{2}\left(\frac{1}{I_z}-\frac{1}{I}\right)$ (d) $\frac{\hbar^2}{2I}\ell(\ell+1)+\frac{\hbar^2 m_l^2}{2}\left(\frac{1}{I_z}+\frac{1}{I}\right)$

25. CO_2 molecule has the first few energy levels uniformly separated by approximately 2.5 meV. At a temperature of 300 K, the ratio of the number of molecules in the 4th excited state to the number in the 2nd excited state is about. **[GATE 2010]**
(a) 0.5 (b) 0.6 (c) 0.8 (d) 0.9

26. The moment of inertia of a rigid diatomic molecule A is 6 times that of another rigid diatomic molecule B. If the rotational energies of the molecules are equal, then the corresponding values of the roational quantum numbers J_A and J_B are **[GATE 2014]**

(a) $J_A = 2, J_B = 1$ (b) $J_A = 3, J_B = 1$ (c) $J_A = 5, J_B = 0$ (d) $J_A = 6, J_B = 1$

27. In a rigid-rotator of mass *M*, if the energy of the first excited state is 1 *meV*, then the fourth excited state energy (in *meV*) is________ **[GATE 2015]**

28. Typical energy of the rotational modes in a polyatomic molecule like NH_3 is:

(a) 10^{-6}eV (b) 10^{-3}eV (c) 10^{-4}eV (d) 1 eV

29. Which one of the following molecules does not exhibit a rotational spectrum?

(a) H_2 (b) CO (c) HCl (d) HBr

30. The molecular spectra of two linear molecules O-C-O and O-C-S are recorded in the microwave region. Which one of the following statement is correct?

(a) Both the molecules would show absorption lines
(b) Both the molecules woulb not show absorption lines
(c) O-C-O would show absorption lines, but not O-C-S.
(d) O-C-S would show absorption lines, but not O-C-O.

31. The rotational energy levels of a rigid diatomic molecules are given by $E_J = B_e J(J+1)$ where J is the rotational quantum number and B_e is the constant. The rotational absorption spectrum of the molecules therefore consists of

(a) One resonance line
(b) Lines that are equally spaced.
(c) Lines where the spacing increases with frequency
(d) Lines where the spacing decreases with frequency.

32. The sharpest sepctrum lines in the microwave rotational spectrum are observed when the sample is a

(a) solid (b) liquid (c) liquid crystal (d) gas

33. The H_2 molecule has a reduced mass $M = 8.35 \times 10^{-28}$ kg and an equilibrium internuclear distance $R = 0.742 \times 10^{-10}$ m. The rotational energy in terms of the rotational quantum number J is : **[JEST 2016]**

(a) $E_{\text{rot}}(J) = 7J(J-1)$ meV (b) $E_{\text{rot}}(J) = \frac{5}{2}J(J+1)$ meV

(c) $E_{\text{rot}}(J) = 7J(J+1)$ meV (d) $E_{\text{rot}}(J) = \frac{5}{2}J(J-1)$ meV

34. Two homonuclear diatomic molecules produce different rotational spectra, even through the atoms are known to have identical chemical properties. This leads to the conclusion that the atoms must be **[TIFR 2016]**

(a) isotopes, i.e. with the same atomic number (b) isobars, i.e. with the same atomic weight
(c) isotones, i.e. with the same neutron number (d) isomers, i.e. with the same atomic number and weight

35. Which one of the following molecules does not exhibit a rotational spectrum?

(a) H_2 (b) CO (c) HCl (d) HBr

36. The pure rotational levels of a molecule in the far-infrared region follows the formula F(J) = BJ (J+ 1), where F(J) is the energy of the rotational level with quantum number J and B is the rotational constant. The lowest rotational energy gap in rotational Raman spectrum is :

(a) 2B (b) 4B (c) 6B (d) 8B

37. You are shown a spectrum consisting of a series of equally spaced lines. This could be

(a) The rotational spectrum CO. (b) The vibrational spectrum of N_2.
(c) The NMR spectrum of CH_4 (d) The Mossbauer spectrum of Fe_3O_4.

38. The separation between neighbouring absorption lines in a pure rotational spectrum of the hydrogen bromide (HBr) molecule is 2.23 MeV. If this molecule is considered as a rigid rotor and the atomic mass number of Br is 80, the corresponding absorption line separation in deuterium bromide (DBr) molecule, in units of MeV, would be **[TIFR 2017]**

(a) 2.234 (b) 1.115 (c) 1.128 (d) 4.461

39. The strongest three lines in the emission of an interstellar gas cloud are found to have wavelengths λ_0, $2\lambda_0$ and $6\lambda_0$ respectively, where λ_0 is a known wavelength. From this we can deduce that the radiating particles in the cloud behave like

(a) Free particles (b) Particles in a box

(c) Harmonic oscillators (d) Rigid rotators

ANSWER KEY

1. (a) 2. (c) 3. (d) 4. (c) 5. (a) 6. (a,d) 7. (b)
8. (a) 9. (b) 10. (b) 11. (c) 12. (c) 13. (b) 14. (a)
15. (b) 16. (d) 17. (c) 18. (b) 19. (b) 20. (b) 21. (d)
22. (a) 23. (a) 24. (a) 25. (c) 26. (b) 27. (10) 28. (c)
29. (a) 30. (d) 31. (b) 32. (a) 33. (a) 34. (a) 35. (a)
36. (c) 37. (a) 38. (c) 39. (d)

39. The strongest three lines in the emission of an interstellar gas cloud are found to have wavelengths λ_0, $2\lambda_0$ and $6\lambda_0$ respectively, where λ_0 is a known wavelength. From this we can deduce that he radiating particles in the cloud behave like

(a) free particles
(b) Particles in a box
(c) Harmonic oscillators
(d) Rigid rotators

ANSWER KEY

1. (a) 2. (c) 3. (d) 4. (c) 5. (a) 6. (a,d) 7. (b)
8. (a) 9. (b) 10. (b) 11. (c) 12. (c) 13. (b) 14. (a)
15. (b) 16. (d) 17. (c) 18. (b) 19. (b) 20. (b) 21. (d)
22. (a) 23. (a) 24. (a) 25. (c) 26. (b) 27. (10) 28. (c)
29. (a) 30. (d) 31. (b) 32. (a) 33. (a) 34. (a) 35. (a)
36. (c) 37. (a) 38. (c) 39. (d)

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Assignment-6 : Vibrational Spectra

1. Which of the following molecules has the lowest vibrational frequency?
(a) $^{4}H^{35}Cl$ (b) $^{2}H^{35}Cl$ (c) $^{4}H^{36}Cl$ (d) $^{4}H^{37}Cl$

Linked Answer Type Q. 2 and Q. 3

The IR spectrum of a diatomic molecule exhibits transitions at 2144 cm^{-1}, 4262 cm^{-1}, 6354 cm^{-1} corresponding to the excitations from the ground state to the first, second, third vibration states respectively.

2. The fundamental transition (in cm^{-1}) of the diatomic molecule is at
(a) 2157 (b) 2170 (c) 2183 (d) 2196

3. The anharmonicity constant (in cm^{-1}) of the diatomic molecule is
(a) 0.018 (b) 0.012 (c) 0.006 (d) 0.003

4. The vibrational energy levels $v'' = 0$ and $v' = 1$ of a diatomic molecule are separated by 2143 cm^{-1}. It's anharmonicity $(\omega_e x_e)$ is 14 cm^{-1}. The values of ω_e (in cm^{-1}) and first vertone (in cm^{-1}) of this molecule are respectively
(a) 2143, 4286 (b) 2157, 4286 (c) 2157, 4314 (d) 2171,4258

5. The Infrared spectrum of HCl gas shows an absorption band centered at 2885 cm^{-1}.The zero point energy of HCl molecule under harmonics oscillator approximation is
(a) $2.8865\times10^{-22}J$ (b) $2.8865\times10^{-20}J$ (c) $5.7730\times10^{-20}J$ (d) $5.7730\times10^{-22}J$

6. Overtones are observed in the vibrational spectra of diatomic molecules when
(a) Anharmonicity is large
(b) Anharmonicity is absent
(c) Vibrational and rotational modes are coupled
(d) An alternating electric field is applied

Common Data for Q. 7 and Q. 8

The fundamental band and the first overtone for CO molecule is centered at 2143.3 cm^{-1} and 4259.7 cm^{-1} respectively. (Given: The reduced mass of CO molecule is $1.14\times10^{-26}\,kg$)

7. The vibrational frequency of CO molecule is
(a) $2170\ cm^{-1}$ (b) $2467\ cm^{-1}$ (c) $1108\ cm^{-1}$ (d) $3456\ cm^{-1}$

8. The anharmonicity constant of CO molecule will be
(a) $6.8\ cm^{-1}$ (b) $10.2\ cm^{-1}$ (c) $13.5\ cm^{-1}$ (d) $19.5\ cm^{-1}$

9. The ratio between the fundamental vibrational frequencies of HI and DI is
(a) $\frac{1}{2}$ (b) 2 (c) $\frac{1}{\sqrt{2}}$ (d) $\sqrt{2}$

10. Replacement of hydrogen by deuterium atom bound to a heavy atom X in a polyatomic molecule would reduce the vibrational frequency of X-H streching by a factor of
(a) 2 (b) $\sqrt{2}$ (c) 4 (d) 1.3

11. The R branch in the vibrational spectra of AX molecule exhibits a set equally spaced lines with a separation of 10 cm^{-1}. The rotational constant of AX molecule is
(a) 10 cm^{-1} (b) 20 cm^{-1} (c) 5 cm^{-1} (d) 15 cm^{-1}

12. The vibartional-rotational energy of a diatomic molecule may be written as (where ν is the frequency of vibration and I is the moment of inertia of the molecule)

(a) $\left(n+\frac{1}{2}\right)h\nu+\frac{h^2}{2I}J(J+1)$ $[n=1,2,3.....\text{ and } J=0,1,2,3....]$

(b) $\left(n+\frac{1}{2}\right)h\nu+\frac{h^2}{2I}J(J+1)$ $[n=0,1,2,3.....\text{ and } J=0,1,2,3....]$

(c) $\left(n+\frac{1}{2}\right)h\nu+\frac{h^2}{2I}M^2$ $[n=1,2,3.....\text{ and } M=0,\pm1,\pm2,\pm3....]$

(d) $\left(n+\frac{1}{2}\right)h\nu+\frac{h^2}{2I}M^2$ $[n=0,1,2,3.....\text{ and } M=0,1,2,3....]$

13. The selection rules for the appearances of P branch in the rotational vibrational absorption spectra of a diatomic molecule with rigid rotator- harmonic oscillator model are
(a) $\Delta v=\pm1, \Delta J=\pm1$ (b) $\Delta v=+1, \Delta J=+1$ (c) $\Delta v=+1, \Delta J=-1$ (d) $\Delta v=-1, \Delta J=-1$

14. The roatational constant for CO molecule in the ground state and the first excited states are 1.9 cm^{-1} and 1.6 cm^{-1} respectively. The percentage change in the internuclear distance due to vibrational excitation is
(a) 9 (b) 30 (c) 16 (d) 0

15. In the IR spectrum of $\left[Co(CN)_5H\right]^{3-}$ the $Co-H$ strech is observed at 1840 cm^{-1}. The $Co-D$ strech in $\left[Co(CN)_5D\right]^{3-}$ will appear at nearly
(a) 1300 cm^{-1} (b) 1400 cm^{-1} (c) 1500 cm^{-1} (d) 1600 cm^{-1}

16. The fundamental mode of HCl occurs at $2886\ cm^{-1}$. The fundamental mode of DCl will occur
(a) 1367 cm^{-1} (b) 2069 cm^{-1} (c) 2778 cm^{-1} (d) 3024 cm^{-1}

17. The moment of inertia of the HCl^{35} molecule in the $v=0$ and $v=1$ levels is $20.8\times10^{-7}kg-m^2$. The wave number difference between the $R(0)$ and $P(1)$ lines of the fundamemtal band for HCl^{35} molecule is
(a) 4164 m^{-1} (b) 1041 m^{-1} (c) 2082 m^{-1} (d) 5205 m^{-1}

18. For a diatomic molecule with the vibrational quantum number n and rotational quantum number J, the vibrational level spacing $\Delta E_n = E_n - E_{n-1}$ and the rotational level spacing $\Delta E_J = E_J - E_{J-1}$ are approximately

[GATE 2005]

(a) $\Delta E_n = \text{constant}, \Delta E_J = \text{constant}$ (b) $\Delta E_n = \text{constant}, \Delta E_J \propto J$

(c) $\Delta E_n \propto n, \Delta E_J \propto J$ (d) $\Delta E_n \propto n, \Delta E_J \propto J^2$

19. Which one of the following statement is INCORRECT in vibrational spectroscopy with anharmonicity?
(a) The selection rule for vibrational spectroscopy is $\Delta v = \pm1, \pm2,.....$ **[GATE 2008]**
(b) Anharmonicity leads to multiple absorption lines
(c) The intensities of hot band lines are stronger than the fundamental absorption.
(d) The frequencies of hot band lines are smaller than the fundamental absorption.

20. The equilibrium vibration frequency for an oscillator observed at 2990cm^{-1}. The ratio of the frequencies corresponding to the first and the fundamental spectral lines is 1.96. Considering the oscillator to be anharmonic, the anharmonicity constant is **[GATE 2012]**
(a) 0.005 (b) 0.02 (c) 0.05 (d) 0.1

21. If the leading anharmonic correction to the energy of the n-th vibrational level of a diatomic molecule is $-x_e\left(n+\frac{1}{2}\right)^2 \hbar\omega$ with $x_e = 0.001$, the total number of energy levels possible is approximately

(a) 500 (b) 1000 (c) 250 (d) 750 **[NET Dec. 2014]**

22. There is no infrared absorption for nitrogen molecule because:

(a) Its polarizability is zero (b) It has no vibrational levels
(c) It has no rotational levels (d) Its dipole moment is zero

23. Infrared absorption can be observed in which of the following molecules?
(a) N_2 (b) O_2 (c) HCl (d) C_2

24. All vibrations producing a change in the electric dipole moment of a molecule yield
(a) Raman spectra (b) Infrared spectra
(c) Ultra-violet spectra (d) X-ray spectra

25. The typical wavelengths emitted by diatomic molecules in purely vibrational and purely rotational transitions are respectively in the region of
(a) Infrared and visible (b) Visible and infrared
(c) Infrared and microwave (d) Microwave and infrared

26. Which of the diatomic molecules H_2, HD, D_2 and HT has the highest vibrational frequency?

(a) HT (b) D_2 (c) HD (d) H_2

27. The spacing between vibrational energy levels in CO molecule is found to be 8.441×10^{-2} eV. Given that the reduced mass of CO is 1.14×10^{-26} kg, Planck's constant is 6.626×10^{-34} Js and $1\text{eV} = 1.6 \times 10^{-19}$J. The force constant of the bond is CO molecule is
(a) 1.87 N/m (b) 18.7 N/m (c) 187 N/m (d) 1870 N/m

28. A diatomic molecule has vibrational states with energies $E_v = \hbar\omega\left(v+\frac{1}{2}\right)$ and rotational states with energies $E_j = Bj(j+1)$, where v and j are non-negative integers. Consider the transitions in which both the initial and final states are restricted to $v \le 1$ and $j \le 2$ and subject to the selection rules $\Delta v = \pm 1$ and $\Delta j = \pm 1$. Then the largest allowed energy of transition is **[NET June 2015]**
(a) $\hbar\omega - 3B$ (b) $\hbar\omega - B$ (c) $\hbar\omega + 4B$ (d) $2\hbar\omega + B$

29. Infrared absorption can be observed in which of the following molecules?
(a) N_2 (b) O_2 (c) HCl (d) C_2

30. All vibrations producing a change in the electric dipole moment of a molecule yield
(a) Raman spectra (b) Infrared spectra
(c) Ultra-violet spectra (d) X-ray spectra

31. The typical wavelengths emitted by diatomic molecules in purely vibrational and purely rotational transitions are respectively in the region of
(a) Infrared and visible (b) Visible and infrared
(c) Infrared and microwave (d) Microwave and infrared

32. The unequal spacing in the vibrational energy levels of a diatomic molecule would be due to the
(a) Presence of anharmonic terms in the potential energy.
(b) Finite mass of the nuclei.
(c) Frank-Condon principle.
(d) Harmonic nature of the potential energy.

33. The expression for the second overtone frequency in the vibrational absorption spectra of a diatomic molecules in terms of the harmonic frequency ω_e and anharmonicity constant x_e is **[GATE 2018]**

(a) $2\omega_e(1-x_e)$ (b) $2\omega_e(1-3x_e)$ (c) $3\omega_e(1-2x_e)$ (d) $3\omega_e(1-4x_e)$

ANSWER KEY

1. (d)	**2. (b)**	**3. (c)**	**4. (d)**	**5. (b)**	**6. (a)**	**7. (a)**
8. (c)	**9. (d)**	**10. (d)**	**11. (b,c)**	**12. (b)**	**13. (c)**	**14. (a)**
15. (a)	**16. (b)**	**17. (d)**	**18. (b)**	**19. (c)**	**20. (b)**	**21. (b)**
22. (d)	**23. (c)**	**24. (b)**	**25. (c)**	**26. (d)**	**27. (c)**	**28. (c)**
29. (c)	**30. (b)**	**31. (c)**	**32. (c)**	**33. (d)**		

CSIR-UGC-NET/JRF | GATE PHYSICS

Assignment-7 : Electronic and Raman Spectra

1. In an experiment, the exciting line of of a sample is observed at 5460 A^0 and stokes line is observed at 5520 A^0. The wavelength of the anti-stokes line is
(a) 5420 A^0 (b) 5401 A^0 (c) 5380 A^0 (d) 5580 A^0

2. In the Rotational Raman spectrum of HCl molecule, the displacemnts from the exciting line are represented by

$$\Delta\nu = \pm(120+80J)\,cm^{-1}$$

The moment of inertia of the molecule is

(a) $1.4\times10^{-47}\ kg-m^2$ (b) $2.8\times10^{-47}\ kg-m^2$

(c) $4.2\times10^{-47}\ kg-m^2$ (d) $5.6\times10^{-47}\ kg-m^2$

Common Data for Q.3 and Q.4

The rotational Raman displacement for HCl molecule is 41.6 cm^{-1}.

(Given: The reduced mass of HCl molecule is $1.62\times10^{-27}\,kg$)

3. The moment of inertia of HCl molecule is
(a) $1.34\times10^{-40}\,kg-m^2$ (b) $2.7\times10^{-40}\,kg-m^2$ (c) $1.34\times10^{-47}\,kg-m^2$ (d) $2.7\times10^{-47}\,kg-m^2$

4. The internuclear distance between the atoms of the molecule is
(a) $0.48A^0$ (b) $0.84A^0$ (c) $1.30A^0$ (d) $1.95A^0$

5. The selection rule for the allowed rotational Raman lines is
(a) $\Delta J=0,\pm2$ (b) $\Delta J=\pm1$ (c) $\Delta J=0$ (d) $\Delta J=0,\pm1,\pm2$

6. The first line in the rotational Raman spectra of a diatomic molecule appears with a stokes shift of 12 cm^{-1}. The stokes shift for the second line is
(a) 36 cm^{-1} (b) 24 cm^{-1} (c) 18 cm^{-1} (d) 20 cm^{-1}

7. When $^{14}N_2$ (with rotational constant Of 1.99 cm^{-1}) is exposed to 340 nm light, then the stokes and anti-stokes line for the molecule in the second rotational state can be observed at
(a) 29412 cm^{-1}, 29410 cm^{-1} (b) 29366 cm^{-1}, 29402 cm^{-1}
(c) 14779 cm^{-1}, 58529.9 cm^{-1} (d) 29384 cm^{-1}, 29424 cm^{-1}

Common Data for Q. 8 and Q. 9

8. The rotational constant of $^{14}N_2$ is 2 cm^{-1}. The wave number of the incident radiation in a Raman spectrometer is 20487 cm^{-1}. The wave number of the first scattered Stokes line (in cm^{-1}) of $^{14}N_2$ is
(a) 20479 (b) 20475 (c) 20499 (d) 20495

9. The rotational Stokes line is expected at (in cm^{-1})
(a) 20467 (b) 20469 (c) 20471 (d) 20475

10. A laser operating at 500 nm is used to excite a molecule. If the Raman shift is observed at 770 cm^{-1}, the approximate positions of the ani-Stokes and the Stokes lines are **[NET Dec. 2011]**
(a) 481.5 nm and 520 nm (b) 481.5 nm and 500 nm
(c) 500 nm and 520 nm (d) 500 nm and 600 nm

11. Light of wavelength 1.5 μm incident on a material with a characteristic Raman frquency of 20×10^{12} Hz results in a stokes-shifted line of wavelength $\left[\text{Given} : c = 3 \times 10^8 \text{m.s}^{-1}\right]$ **[GATE 2002]**

(a) 1.47 μm (b) 1.57 μm (c) 1.67 μm (d) 1.77 μm

12. In the Raman scattering experiment, light of frequency ν from a laser is scatteered by diatomic molecules having moment of inertia I. The typical Raman shifted frequency depends on **[GATE 2005]**

(a) ν and I (b) only ν (c) only I (d) neither ν nor I

13. A vibrational-electronic spectrum of homonuclear binary molecules, involving electronic ground state ε'' and excited ε', exhibits a continuum at $\bar{\upsilon}$ cm^{-1}. If the total energy of the dissociated atoms in the excited state exceeds the total energy of the dissociated atoms in the ground state by E_{ex}cm^{-1}, then dissociation energy of the molecule in the ground state is : **[GATE 2006]**

(a) $(\bar{\upsilon} + E_{ex})/2$ (b) $(\bar{\upsilon} - E_{ex})/2$ (c) $(\bar{\upsilon} - E_{ex})$ (d) $\sqrt{(\bar{\upsilon}^2 - E_{ex}{}^2)}$

14. A pure rotational Raman spectrum of a linear diatomic molecule is recorded using electromagnetic radiation of frequency υ_e. The frequency of two consecutive stokes lines are : **[GATE 2008]**

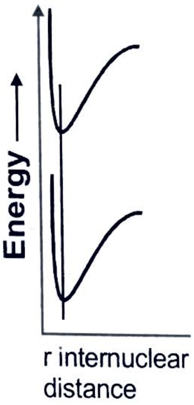
(a) $\upsilon_e - 10B, \upsilon_e - 14B$ (b) $\upsilon_e - 2B, \upsilon_e - 4B$

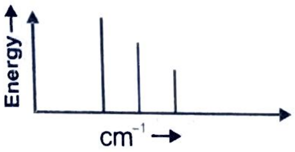
(c) $\upsilon_e + 10B, \upsilon_e + 14B$ (d) $\upsilon_e + 2B, \upsilon_e + 4B$

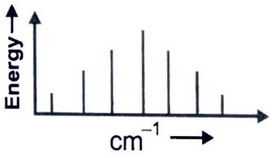
15. The separation between the first stokes and corresponding anti-stokes lines of the rotational Raman spectrum in terms of the rotational constant, B is : **[GATE 2009]**

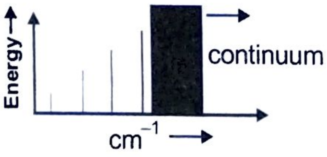
(a) 2B (b) 4B (c) 6B (d) 12B

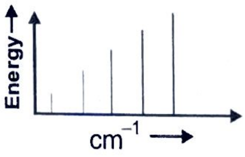
16. In a diatomic molecule, the internuclear separation of the ground and first excited electronic state are the same as shown in the figure. If the molecule is initially in the lowest vibrational state of the ground state, then the absorption spectrum will appear as



(a) 

(b) 

(c) 

(d) 

[GATE 2009]

17. The far infrared rotational absorption spectrum of diatomic molecule shows equidistant blines with spacing 20 cm^{-1}. The position of the first stokes line in the rotational Raman spectrum of the molecule is **[GATE 2011]**

(a) 20 cm^{-1} (b) 40 cm^{-1} (c) 60 cm^{-1} (d) 120 cm^{-1}

18. The first Stokes line of a rotational Raman spectrum is observed at 12.96 cm^{-1}. Considering rigid rotator approximation, the rotational constant is given by **[GATE 2012]**

(a) 6.48 cm^{-1} (b) 3.24 cm^{-1} (c) 2.16 cm^{-1} (d) 1.62 cm^{-1}

19. The excitation wavelength of laser in a Raman effect experiment is 546 *nm*. If the Stokes line is observed at 552 *nm*, then the wave number of the anti-Stokes line (in cm^{-1}) is____________________ **[GATE 2015]**

20. The energy separation between two consecutive stokes lines in Raman Scattering depends on

(a) Energy separation between vibrational levels in the excited state
(b) Wavelength of the incident light
(c) Energy separation between vibrational levels in the ground state
(d) Intensity of the incident light

21. The vibrational constants ω_0 and $\omega_0 x_0$ of HCl are 2937.5 cm^{-1} and 51.6 cm^{-1}. The first Raman stokes line will be observed at (in cm^{-1})

(a) 2989.1 (b) 2885.9 (c) 2834.3 (d) 3040.7

22. The intensity of the electronic 0-0 band of a diatomic molecule is very intense when the minimum of the potential curve for the upper electronic state lies (here r is the internuclear distance).

(a) at the same value r as that of the lower potential curve
(b) at a smaller value of r than that of the lower potential curve
(c) at a larger value of r than that of the lower potential curve
(d) above the dissociation level of the lower potential curve

23. Resonance (NMR, ESR etc.) studies in solids provide information about

(a) The electronic structure of single defects
(b) The motion of the spin or of the surrounding
(c) Collective spin excitations
(d) Internal magnetic fields sampled by the spin

24. The vibrational spectrum of a molecule exhibits a strong line with P and R branches at a frequency u_1 and a weaker line at a frequency u_2. The frequency u_3 isnot shown up. Its vibrational Raman spectrum shows a strongly polarized line at frequency u_3 and no feature at u_1 and u_2

(a) The molecule could be linear
(b) The molecule lacks a center of inversion
(c) $\mathbf{u_1}$ arises from a symmetric stretching mode
(d) $\mathbf{u_3}$ arises from a bending mode

25. Consider the following statements about molecular spectra

P: CH_4 does not give pure rotational Raman lines
Q: SF_6 could be studied by rotational Raman spectroscopy
R: N_2 shows infrared absorption spectrum
S: CH_3CH_3 shows vibrational Raman and infrared absorptin lines
T: H_2O_2 shows pure rotational spectrum

Choose the right combination of correct statements

(a) P and Q (b) P, R and T (c) P, S and T (d) Q and R

26. You are shown a spectrum consisting of a series of equally spaced lines. This could be

(a) The rotational spectrum CO. (b) The vibrational spectrum of N_2.
(c) The NMR spectrum of CH_4 (d) The Mossbauer spectrum of Fe_3O_4.

[GATE 2005]

27. Match the following and choose the correct combination

Group-I	Group-2
P. Atomic configuration $1s^2 2s^2 2p^6 3s^2 3p^6$	1. Na
Q. Strongly electropositive	2. Si
R. Strongly electronegative	3. Ar
S. Covalent bonding	4. Cl

(a) P-1, Q-2, R-3, S-4
(b) P-3, Q-2, R-4, S-1
(c) P-3, Q-1, R-4, S-2
(d) P-3, Q-4, R-1, S-2

28. Match the following: [GATE 2007]

P: Franck-Hertz experiment
1. Electronic excitation of molecules
Q: Hartree-Fock method 2.
Wave function of atom
R: Stern-Gerlach experiment
3. Spin angular momentum of atoms
S: Franck-Condon principle
4. Energy levels in atoms

(a)	(b)	(c)	(d)
P-4	P-1	P-3	P-4
Q-2	Q-4	Q-2	Q-1
R-3	R-3	R-4	R-3
S-1	S-2	S-1	S-2

29. The number of fundamental vibrational modes of CO_2 molecule is :
(a) Four: 2 are Raman active and 2 are infrared active
(b) Four: 1 is Raman active and 3 are infrared active
(c) Three: 1 is Raman active and 2 are infrared active
(d) Three: 2 are Raman active and 1 is infrared active

30. Match the typical spectra of stable molecules with the corresponding wave-number rnage [GATE 2010]

1. Electronic spectra
i. 10^6 cm^{-1} and above
2. Rotational spectra
ii. $10^5 - 10^6$ cm^{-1}
3. Molecular dissociation
iii. $10^0 - 10^2$ cm^{-1}

(a) 1–ii, 2–i, 3–iii
(b) 1–ii, 2–iii, 3–i
(c) 1–iii, 2–ii, 3–i
(d) 1–i, 2–ii, 3–iii.

31. If a molecule has a centre of symmetry then
(a) Raman active vibrations are infrared active
(b) Raman active vibrations are infrared inactive and vice versa
(c) some, but not all, of the Raman active vibrations are infrared active
(d) all vibrations are Raman and infrared inactive.

32. Match the typical spectroscopic regions specified in **Group I** With the corresponding type of transitions in **Group II.** [GATE 2012]

Group I	Group II
(P) Infra-red region	(i) electronic transitions involving valence electrons
(Q) Ultraviolet- visible region	(ii) nuclear transitions
(R) X-ray region	(iii) vibrational transitions of molecules
(S) γ -ray region	(iv) transitions involving inner shell electrons

(a) $(P,i);(Q,iii);(R,ii);(S,iv)$
(b) $(P,ii);(Q,iv);(R,i);(S,iii)$
(c) $(P,iii);(Q,i);(R,iv);(S,ii)$
(d) $(P,iv);(Q,i);(R,ii);(S,iii)$

33. Raman effect is suppressed in
(a) semiconductors
(b) dielectrics
(c) metals
(d) insulators

34. Match the phrases in Group I and Group II and identify the correct option. **[GATE 2015]**

Group I	**Group II**
(P) Electron spin resonance (ESR)	(i) radio frequency
(Q) Nuclear magnetic resonance (NMR)	(ii) visible range frequency
(R) Transition between vibrational states of a molecule	(iii) microwave frequency
(S) Electronic transition	(iv) far-infrared range

(a) (P-i), (Q-ii), (R-iii), (S-iv) (b) (P-ii), (Q-i), (R-iv), (S-iii)
(c) (P-iii), (Q-iv), (R-i), (S-ii) (d) (P-iii), (Q-i), (R-iv), (S-ii)

35. The molecule $^{17}O_2$ is **[GATE 2016]**
(a) Raman active but not NMR (nuclear magnetic resonance) active
(b) Infrared active and Raman active but not NMR active
(c) Raman active and NMR active
(d) Only NMR active

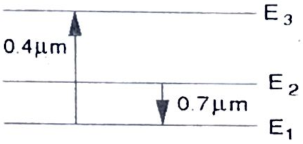
36. Which one of the following gases of diatomic molecules is Raman, infrared, and NMR active?
(a) $^{1}H-^{1}H$ (b) $^{12}C-^{16}O$ (c) $^{1}H-^{35}Cl$ (d) $^{16}O-^{16}O$ **[GATE 2017]**

ANSWER KEY

1. (b) 2. (a) 3. (a) 4. (c) 5. (a) 6. (d) 7. (d)
8. (b) 9. (a) 10. (b,c) 11. (c) 12. (c) 13. (c) 14. (a)
15. (d) 16. (a) 17. (c) 18. (c) 19. (18513 to 18519) 20. (c)
21. (c) 22. (a) 23. (a,b,c,d) 24. (a) 25. (c) 26. (a) 27. (c)
28. (a) 29. (b) 30. (b) 31. (b) 32. (c) 33. (c) 34. (d)
35. (c) 36. (c)

Assignment-8: Laser

1. Consider the energy level diagram (as shown in the figure below) of a typical three level ruby laser system with 1.6×10^{19} Chromium ions per cubic centimeter. All the atoms excited by the $0.4\ \mu m$ radiation decay rapidly to level E_2 which has a lifetime $\tau = 3ms$ **[CSIR June 2011]**



A. Assuming that there is no radiation of wavelength $0.7\ \mu m$ present in the pumping cycle and that the pumping rate is R atoms per cm³, the population density in the level N_2 builds up as:

(a) $N_2(t) = R\tau\left(e^{t/\tau} - 1\right)$
(b) $N_2(t) = R\tau\left(1 - e^{-t/\tau}\right)$
(c) $N_2(t) = \frac{Rt^2}{\tau}\left(1 - e^{-t/\tau}\right)$
(d) $N_2(t) = Rt$

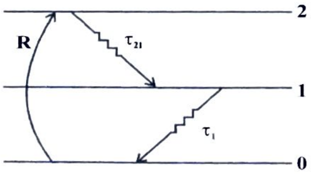
B. The minimum pump power required (per cubic centimeter) to bring the system to transparency, i.e. zero gain, is

(a) 1.52 kW
(b) 2.64 kW
(c) 0.76 kW
(d) 1.32 kW

2. Consider a hydrogen atom undergoing a $2P \rightarrow 1S$ transition. The lifetime t_{sp} of the 2P state for spontaneous emission is 1.6 ns and the energy difference between the levels is 10.2 eV. Assuming that the refractive index of the medium $n_0 = 1$, the ratio of the Einstein coefficients for stimulated emission $B_{21}(\omega)/A_{21}(\omega)$ is given by **[CSIR Dec. 2012]**

(a) $0.683\times10^{12}\ m^3J^{-1}s^{-1}$
(b) $0.146\times10^{-12}\ J\ s\ m^{-3}$
(c) $6.83\times10^{12}\ m^3\ J^{-1}\ s^{-1}$
(d) $1.463\times10^{-12}\ J\ s\ m^{-3}$

3. Consider the energy level diagram shown below, which corresponds to the molecular nitrogen laser. **[CSIR Dec. 2012]**



If the pump rate R is 10^{20} atoms cm^{-3} s^{-1} and the decay routes are as shown with $\tau_{21} = 20$ ns and $\tau_1 = 1\ \mu s$, the equilibrium populations of states 2 and 1 are, respectively,

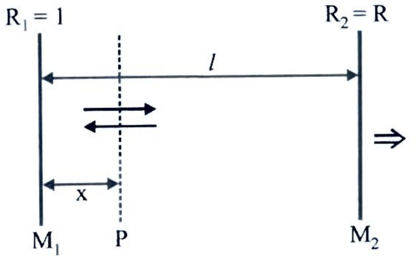
(a) 10^{14} cm^{-3} and 2×10^{12} cm^{-3}
(b) 2×10^{12} cm^{-3} and 10^{14} cm^{-3}
(c) 2×10^{12} cm^{-3} and 2×10^{6} cm^{-3}
(d) zero and 10^{20} cm^{-3}

4. Consider a He-Ne laser cavity consisting of two mirrors of reflectivities $R_1 = 1$ and $R_2 = 0.98$. The mirrors are separated by a distance $d = 20$ cm and the medium in between has a refractive index $n_0 = 1$ and absorption coefficient $\alpha = 0$. The values of the separation between the modes δv and the width Δv_p of each mode of the laser cavity are: **[NET Dec. 2012]**

(a) $\delta v = 75$ kHz, $\Delta v_p = 24$ kHz (b) $\delta v = 100$ kHz, $\Delta v_p = 100$ kHz

(c) $\delta v = 750$ MHz, $\Delta v_p = 2.4$ MHz (d) $\delta v = 2.4$ MHz, $\Delta v_p = 750$ MHz

5. Consider the laser resonator cavity shown in the figure.
If I_1 is the intensity of the radiation at mirror M_1 and α is the gain coefficient of the medium between the mirrors, then the energy density of photons in the plane P at a distance x from M_1 is



[NET June 2013]

(a) $(I_1/c)e^{-\alpha x}$ (b) $(I_1/c)e^{\alpha x}$ (c) $(I_1/c)(e^{\alpha x} + e^{-\alpha x})$ (d) $(I_1/c)e^{2\alpha x}$

6. The electronic energy levels in a hydrogen atom are given by $E_n = -13.6/n^2$ eV. If a selective excitation to the n = 100 level is to be made using a laser, the maximum allowed frequency line-width of the laser is **[NET June 2013]**

(a) 6.5 MHz (b) 6.5 GHz (c) 6.5 Hz (d) 6.5 kHz

7. Two monochromatic sources, L_1, and L_2, emit light at 600 and 700 nm, respectively. If their frequency bandwidths are 10^{-1} and 10^{-3} GHz, respectively, then the ratio of linewidth of L_1 and L_2 is approximately **[NET Dec. 2013]**

(a) 100 : 1 (b) 1 : 85 (c) 75 : 1 (d) 1 : 75

8. A gas laser cavity has been designed to operate at $\lambda = 0.5\mu m$ with a cavity length of 1m. With this set-up, the frequency is found to be larger than the desired frequency by 100 Hz. The change in the effective length of the cavity required to retune the laser is **[NET Dec. 2013]**

(a) -0.334×10^{-12} m (b) 0.334×10^{-12} m

(c) 0.167×10^{-12} m (d) -0.167×10^{-12} m

9. A three level system of atoms has N_1 atoms in level E_1, N_2 in level E_2, and N_3 in level E_3 ($N_2 > N_1 > N_3$ and $E_1 < E_2 < E_3$). Laser emission is possible betwen the levels **[GATE 2005]**

(a) $E_3 \rightarrow E_1$ (b) $E_2 \rightarrow E_1$ (c) $E_3 \rightarrow E_2$ (d) $E_2 \rightarrow E_3$

10. Which one of the following electronic transitions in Neon is NOT responsible for LASER action in a helium-neon laser? **[GATE 2006]**

(a) 6s → 5p (b) 5s → 4p (c) 5s → 3p (d) 4s → 3p

11. In a He-Ne laser, the laser transition takes place in **[GATE 2007]**

(a) He only (b) Ne only

(c) Ne first, then in He. (d) He first, then in Ne

12. The coherence length of laser light is : **[GATE 2008]**
(a) Directly proportional to the length of the active medium
(b) Directly proportional to the width of the spectral line
(c) Inversely proportional to the width of the spectral line
(d) Inversely proportional to the length of the active lasing medium

13. When the refractive index μ of the active medium changes by Δμ in a laser resonator of length L, the change in the spectral spacing between the longitudinal modes of the laser is (c is the speed of light in free space) **[GATE 2008]**

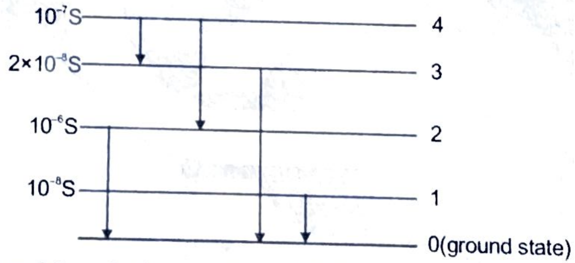
(a) $\frac{c}{2(\mu+\Delta\mu)L}$ (b) $\frac{c}{2\Delta\mu L}$ (c) $\frac{c}{2L}\frac{\Delta\mu}{\mu(\mu+\Delta\mu)}$ (d) zero

14. A collection of N atoms is exposed to a strong resonant electromagnetic radiation with N_g atoms in the ground state and N_e atoms in the excited state, such that $N_g + N_e = N$. This collection of two–level atoms will have the following population distribution. **[GATE 2010]**

(a) $N_g << N_e$ (b) $N_g >> N_e$ (c) $N_g \approx N_e \approx N/2$ (d) $N_g - N_e \approx N/2$

15. The population inversion in a two level laser material CANNOT be achieved by optical pumping because **[GATE 2011]**
(a) The rate of upward transitions is equal to the rate of downward transitions.
(b) The upward transitions are forbidden but downward transitions are allowed.
(c) The upward transitions are allowed but downward transitions are forbidden.
(d) The spontaneous decay rate of the higher level is very low.

16. Five energy levels of a system including the ground state are shown below. Their lifetimes and the allowed electric dipole transitions are also marked.



Which one of the following transitions is the most suitable for a continuous wave (CW) laser?
(a) $1 \to 0$ (b) $2 \to 0$ (c) $4 \to 2$ (d) $4 \to 3$

17. For an atom with two energy levels placed in a cavity containing blackbody radiation, the ratio of the probabilities for spontaneous emission and stimulated emission is given by $\frac{A}{B} = \frac{8\pi v^3}{c^3}$, where A and B are the corresponding Einstein coefficients and v is the frequency of the photon emitted. The probability of spontaneous emission.
(a) Is independent of the energy difference between the two levels.
(b) Increases with the energy difference between the two levels.
(c) Decreases with the energy difference between the two levels.
(d) Is zero.

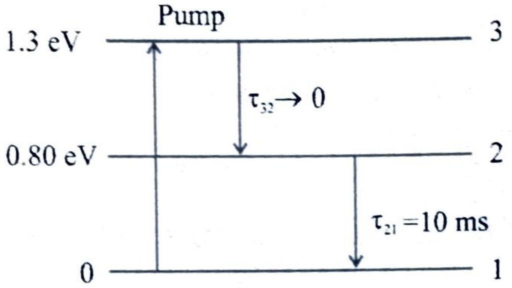
18. The mirrors of a laser cavity are separated by a distance L. If T is the time taken by the light to travel from one mirror to the other and back, the mode separation is:

(a) $\frac{1}{T}$ (b) $\frac{2}{T}$ (c) $\frac{1}{2T}$ (d) $\frac{1}{\sqrt{2}\,T}$

19. The central wavelength of a $0.6\ \mu m$ wavelength laser corresponds to the m^{th} cavity mode of a resonator cavity of length 6 cm. The mode number m is

(a) 1000 (b) 2×10^4 (c) 2×10^5 (d) 200

20. The typical energy level diagram for Erbium ions in a glass is shown below.



For an Erbium ion concentration of ρ ions/cm^3, the pump power needed for population inversion is

(a) $80\ \rho\ \text{eV}/\text{cm}^3\text{s}$ (b) $40\ \rho\ \text{eV}/\text{cm}^3\text{s}$ (c) $130\ \rho\ \text{eV}/\text{cm}^3\text{s}$ (d) $65\ \rho\ \text{eV}/\text{cm}^3\text{s}$

21. A He-Ne laser on transition from 3s to 2p level gives a laser emission of wavelength 632.8 nm. If the 2p level has energy 9.5 eV. The minimum pumping energy required is (assume there is no loss)

(a) 6.7 eV (b) 8.9 eV (c) 11.5 eV (d) 13.9 eV

22. A lamp emits a radiation of wavelength 500 nm at a temparature of 1000K. The ratio of the Stimulated emission rate and spontaneous emission rate will be of the order of

(a) 10^{-7} (b) 10^{-9} (c) 10^{-11} (d) 10^{-13}

23. The temparature at which stimulated emission rate and spontaneous emission rates are equal $(\lambda = 500\ nm)$, is

(a) 41. 6 K (b) 83.2 K (c) 124.8 K (d) 166.4 K

24. Consider an optical resonator of length 0.3 m. The number of the modes in the wavelength range 2 nm centered about 500 nm, will be

(a) 3600 (b) 4200 (c) 4800 (d) 5400

25. The number of photons emitted per second from a 1 Watt Ar-ion laser operating at 488.0 nm is approximately

(a) 10.23×10^{19} (b) 2.46×10^{18} (c) 10.23×10^{17} (d) 2.46×10^{15}

26. Spectral line width of the He-Ne laser is 0.01 nm and the cross sectional area of the beam is 0.01 cm^2. If the output power is 1 milli Watt, the radiation intensity per unit wavelength (in Watt/cm^3) is:

(a) 10^{10} (b) 10^8 (c) 10^{-8} (d) 10^{-10}

27. In which of the following lasers can the wavelength not be tuned?

(a) semiconductor laser (b) Dye laser
(c) Ti: Sapphire laser (d) Ruby laser

28. The emission wavelength for the transition ${}^1D_2 \to {}^1F_3$ is 3122 Å. The ratio of populations of the final to the initial states at a temperature 5000 K is $(h = 6.626\times10^{-34}\ J.s, c = 3\times10^8\ m/s,\ k_B = 1.380\times10^{-23}\ J/K)$

(a) 2.03×10^{-5} (b) 4.02×10^{-5} (c) 7.02×10^{-5} (d) 9.83×10^{-5}

29. A He-Ne laser operates by using two energy levels of Ne separated by 2.26 eV. Under steady state conditions of optical pumping, the equivalent temperature of the system at which the ratio of the number of atoms in the upper state to that in the lower state will be 1/20, is approximately (the Boltzmann constant $k_B = 8.6\times10^{-5}$eV/K). **[NET June 2015]**

(a) 10^{10} K (b) 10^8 K (c) 10^6 K (d) 10^4 K

30. For a two levels system, the population of atoms in the upper and lower levels are 3×10^{18} and 0.7×10^{18}, respectively. If the coefficient of stimulated emission is 3.0×10^5 m^3/W-s^3 and the energy density is 9.0 J/m^3-Hz, the rate of stimulated emission will be **[NET Dec. 2015]**

(a) 6.3×10^{16} s^{-1}
(b) 4.1×10^{16} s^{-1}
(c) 2.7×10^{16} s^{-1}
(d) 1.8×10^{16} s^{-1}

31. The separation between the energy levels of a two-level atom is 2 eV. Suppose that 4×10^{20} atoms are in the ground state and 7×10^{20} atoms are pumped into the excited state just before lasing starts. How much energy will be released in a single laser pulse ? **[NET June 2016]**

(a) 24.6 J
(b) 22.4 J
(c) 98 J
(d) 48 J

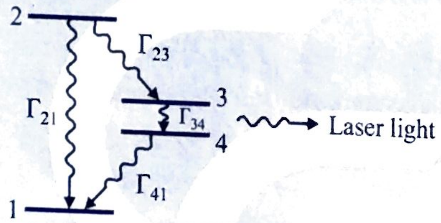
32. A two level system in a thermal (black body) environment can decay from the excited state by both spontaneous and thermally stimulated emission. At room temperature (300 K), the frequency below which thermal emission dominates over spontaneous emission is nearest to **[NET Dec. 2016]**

(a) 10^{13} Hz
(b) 10^{8} Hz
(c) 10^{5} Hz
(d) 10^{11} Hz

33. If the coefficient of stimulated emission for a particular transition is 2.1×10^{19} m^3 W^{-1} s^{-3} and the emitted photon is at wavelength 3000 Å, then the lifetime of the excited state is approximately. **[NET June 2017]**

(a) 20 ns
(b) 40 ns
(c) 80 ns
(d) 100 ns

34. The electronic energy level diagram of a molecule is shown in the following figure. **[NET June 2018]**



Let Γ_{ij} denote the decay rate for a transition from the level i and j. The molecules are optically pumped from level 1 to 2. For the transition from level 3 to level 4 to be a lasing transition, the decay rates have to satisfy

(a) $\Gamma_{21} > \Gamma_{23} > \Gamma_{41} > \Gamma_{34}$
(b) $\Gamma_{21} > \Gamma_{41} > \Gamma_{23} > \Gamma_{34}$
(c) $\Gamma_{41} > \Gamma_{23} > \Gamma_{21} > \Gamma_{34}$
(d) $\Gamma_{41} > \Gamma_{21} > \Gamma_{34} > \Gamma_{23}$

ANSWER KEY

1_A(b) 1_B(d) 2. (c) 3. (b) 4. (c) 5. (c) 6. (b)
7. (c) 8. (d) 9. (b) 10. (a) 11. (b) 12. (c) 13. (c)
14. (c) 15. (a) 16. (b) 17. (a) 18. (a) 19. (c) 20. (d)
21. (c) 22. (d) 23. (a) 24. (c) 25. (b) 26. (b) 27. (d)
28. (c) 29. (d) 30. (c) 31. (d) 32. (a) 33. (c) 34. (c)

LEVEL-2

Solve Yourself

CSIR-UGC-NET/JRF | GATE PHYSICS

LEVEL-2

1. Suppose E_H be the binding energy of hydrogen atom and E_p be the binding energy of the positronium atom which consists of a positron and an electron. Then, which of the following statements is true?

(a) $E_p = E_H$ (b) $E_p = \frac{1}{3}E_H$ (c) $E_p = \frac{1}{2}E_H$ (d) $E_p = 2E_H$

2. Suppose λ_H be the spectral wavelength of hydrogen atom and λ_P be the spectral wavelength of the positronium atom which consists of a positron and an electron. Then, which of the following statements is true?

(a) $\lambda_P = \lambda_H$ (b) $\lambda_P = 2\lambda_H$ (c) $\lambda_P = \frac{1}{2}\lambda_H$ (d) $\lambda_P = \frac{1}{3}\lambda_H$

A μ^- meson (Charge -e, Mass $207m_e$) can be captured by a proton to form a hydrogen-like atom muonic atom.

3. The radius of the first Bohr orbit is
(a) 0.285 pm (b) 0.345 pm (c) 0.415 pm (d) 455 pm

4. The binding energy of the atom is
(a) -1750 eV (b) -2140 eV (c) -2530 eV (d) -3120 eV

5. The first line of the Balmer series is
(a) 6.5 A^0 (b) 18.3 A^0 (c) 25.3 A^0 (d) 35.3 A^0

6. In the hydrogen spectrum, the ratio of the wavelengths for Lyman-α radiation to Balmer-α radiation is
(a) 5/48 (b) 1/3 (c) 5/27 (d) 3

7. If a proton were ten times heavier, then the ground state energy of the electron in a hydrogen atom would have been **[JEST 2014]**
(a) less (b) more
(c) same (d) depends on the electron mass

8. The Bohr model gives the value for the ionisation potential of Li^{2+} ion as
(a) 13.6 eV (b) 27.2 eV (c) 40.8 eV (d) 122.4 eV

9. If the wavelength of the first line of the Balmer series in the hydrogen spectrum is λ, then the wavelength of the first line of the Lyman series is :
(a) $(27/5)\lambda$ (b) $(5/27)\lambda$ (c) $(32/27)\lambda$ (d) $(27/32)\lambda$

10. The radius of a hydrogen atom in its ground state is:

(a) 10^{-4} cm (b) 10^{-6} cm (c) 10^{-8} cm (d) 10^{-10} cm

11. The total energy of the electron in the n^th orbit of hydrogen atom is:

(a) $\frac{e^2}{4\pi\varepsilon_0 r_n}$ (b) $\frac{e^2}{4\pi\varepsilon_0 r^2{}_n}$ (c) $\frac{e^2}{8\pi\varepsilon_0 r_n}$ (d) $-\frac{e^2}{8\pi\varepsilon_0 r_n}$

12. The kinetic energy of an electron in atom is:
(a) Half of its potential energy (b) Twice its potential energy
(c) Equal to its potential energy (d) Thrice its potential energy

13. The total energy of the electron in hydrogen atom is:

(a) $-(13.6/n)$eV (b) $(13.6/n)$eV (c) $-(13.6/n^2)$eV (d) $(13.6/n^2)$eV

14. The range of frequencies of the lines of visible region in hydrogen spectrum is:

(a) $6000\times10^{14}\text{s}^{-1}$ (b) $600\times10^{14}\text{s}^{-1}$ (c) $60\times10^{14}\text{s}^{-1}$ (d) $6\times10^{14}\text{s}^{-1}$

15. The shortest wavelength of Balmer series in hydrogen spectrum is given by the equation

(a) $\frac{1}{\lambda}=R_H\left(\frac{1}{4}-\frac{1}{9}\right)$ (b) $\frac{1}{\lambda}=R_H\left(\frac{1}{2}-\frac{1}{\infty}\right)$ (c) $\frac{1}{\lambda}=R_H\left(1-\frac{1}{\infty}\right)$ (d) $\frac{1}{\lambda}=R_H\left(\frac{1}{4}-\frac{1}{\infty}\right)$

16. If E_H is the binding energy of the electron in the Bohr model of the Hydrogen atom, and both the charge and mass of the electron are doubled, the binding energy becomes

(a) 32 E_H (b) 2 E_H (c) 4 E_H (d) 16 E_H

17. The degeneracy of an first excited state of nitrogen atom having electronic configuration $1s^2 2s^2 2p^2 3d^1$ is

(a) 6 (b) 10 (c) 15 (d) 150 **[GATE 2011]**

18. The electronic configuration of the ground state of a nitrogen is $1s^2\,2s^2\,2p^3$. The degeneracy of this configuration is:

(a) 3 (b) 20 (c) 6 (d) 0

19. What is the maximum number of electrons with spin +1/2 in a p orbital ?

(a) 6 (b) 3 (c) 8 (d) 1

20. The ground state electronic configuration of ^{22}Ti is $[\text{Ar}]3d^2 4s^2$. Which state, in the standard spectroscopic notations, is not possible in this configuration? **[NET June 2016]**

(a) $^1F_3$ (b) $^1S_0$ (c) $^1D_2$ (d) $^3P_0$

21. In the presence of external weak magnetic field, the number of substates into which the state $^4D_{1/2}$ will split, is

(a) 2 (b) 3 (c) 4 (d) none of these

22. The number of Zeeman components for $^3D_3 - {}^3P_2$ transition in one-electron atom will be

(a) 6 (b) 10 (c) 12 (d) 15

23. The Zeeman pattern of a line consists of nine equidistant components. The upper state term is known to be $^3P_2$. The lower state term will be

(a) $^3P_0$ (b) $^2S_{1/2}$ (c) $^3S_1$ (d) $^3P_{3/2}$

24. The number of normal Zeeman splitting components of $^1P \to {}^1D$ transition is **[GATE 2014]**

(a) 3 (b) 4 (c) 8 (d) 9

25. The number of permitted transitions from $^2P_{3/2} \to {}^2S_{1/2}$ in the presence of a weak magnetic field is________________ **[GATE 2015]**

26. Pauli exclusion principle state that

(a) Two electrons can have all the quantum numbers same

(b) No two electrons can have all the quantum numbers same

(c) Particles with integer and half integer spin cannot exist in the same state

(d) None of the above

27. The spectroscopic symbol for the ground state of $_{13}$Al is $^2P_{1/2}$. Under the action of a strong magnetic field (when L-S coupling can be neglected) the ground state energy level will split into

(a) 3 levels (b) 4 levels (c) 5 levels (d) 6 levels

28. The excitation wavelength of laser in a Raman effect experiment is 546 nm. If the Stokes line is observed at 552 nm, then the wave number of the anti-Stokes line (in cm^{-1}) is________ **[GATE 2015]**

29. The J = 0 to J = 1 rotational transition for $^{1}H^{79}Br$ occurs at 500.72 GHz. Assuming the moleule to be a rigid rotator, the J = 3 to J = 4transtition occurs at
(a) 50.1 cm^{-1} (b) 66.8 cm^{-1} (c) 16.7 cm^{-1} (d) 83.5 cm^{-1}

30. Rotational energy of diaatomic molecule is given by $E_{rot} = BhJ(J+1)$ (in Joule). If the rotational constant for H_2 molecule is given as $B = 1.83\times10^{12}\,Hz$, the rotational period of the H_2 molecule in J = 10 level will be
(a) 1.33×10^{-19} sec (b) 5×10^{-15} sec (c) 5.46×10^{-13} sec (d) 7.93×10^{-7} sec

ANSWER KEY : LEVEL-2

1. (c) **2. (b)** **3. (a)** **4. (c)** **5. (d)** **6. (c)** **7. (b)**

8. (d) **9. (b)** **10. (c)** **11. (d)** **12. (a)** **13. (c)** **14. (d)**

15. (d) **16. (a)** **17. (d)** **18. (b)** **19. (b)** **20. (a)** **21. (d)**

22. (d) **23. (c)** **24. (a)** **25. (6)** **26. (b)** **27. (c)** **28. (185)**

29. (b) **30. (b)**